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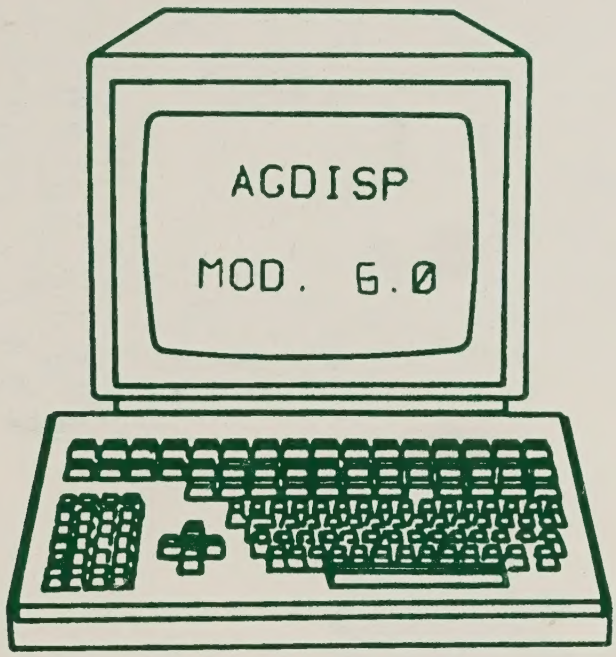
User Manual Extension For The Computer Code AGDISP MOD 6.0



PROGRAM WIND
COOPERATIVE ATMOSPHERIC RESEARCH

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

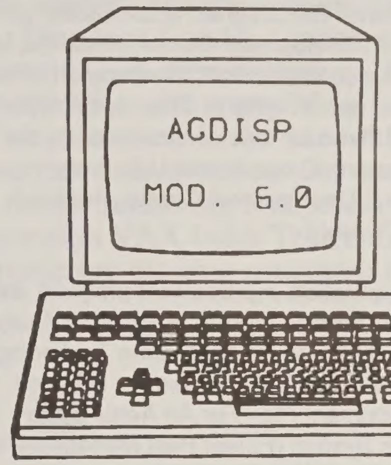
Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

User Manual Extension For The Computer Code AGDISP MOD 6.0



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August 1991

(This work was done under contract 53-0347 9-00076 by Continuum Dynamics, Inc.)

Foreword

This report is published as a part of the USDA Forest Service program to improve aerial application of pesticides, specifically by using pesticides and delivery systems tailored to the forest environment. The program is conducted jointly by the Technology and Development Center, Missoula, MT, and the Forest Pest Management Staff, Washington Office at Davis, CA, under the sponsorship of State and Private Forestry. The MOD 6.0 version was cosponsored by the U.S. Army Dugway Proving Grounds and U.S. Army Chemical Research and Development Center, Research Directorate, Physics Division.

Details of the aerial application improvement program are explained in two Forest Service reports, *A Problem Analysis: Forest and Range Aerial Pesticide Application Technology (MTDC Rept. 7934 2804, July 1979, Missoula, MT) and Recommended Development Plan For An Aerial Spray Planning And Analysis System* (Forest Pest Management Rpt. FFPM 82-2, February 1982, Davis, CA).

A system of computer models has been developed to optimize spray program design and operation and assess environmental risk posed by aerial spray operations. AGDISP is one of these models, and this user's manual covers the most recent version of AGDISP, MOD 6.0.

AGDISP was developed under the leadership of the National Aeronautics and Space Administration with support by the Forest Service to include special forest spray conditions.

When NASA's Agricultural Aviation Program was terminated, the Forest Service continued to support and direct further development and improvements of the AGDISP model.

The changes and additions that have been incorporated into MOD 6.0 are listed on page ii.

The MOD 6.0 is operational on the USDA Forest Service Data General MV-15000 and is installed with GKS graphics, Digital Equipment BAX (with Tektronic 4025 graphics), and the IBM PC/XT/AT personal computers.

Summary

The AGDISP computer program predicts the motion of agricultural material released from aircraft, including the mean position of the material and the position variance about the mean as a result of turbulent fluctuations. Developed under sponsorship by NASA, U. S. Department of Agriculture Forest Service and U. S. Army Dugway Proving Grounds, this program operates efficiently and is user-friendly, with many of its features validated against wind tunnel and flight test data. This document is the Mod 6.0 User Manual to AGDISP, and includes a description of its current enhancements and operating instructions. This version of AGDISP is operational on the following computers: Data General (with GKS graphics); Digital Equipment Corporation VAX (with Tektronix 4025 graphics); and IBM PC/XT/AT/compatibles (with proprietary plotting programs for dot matrix printers).

Modification Level

AGDISP program development has lead to the following released versions:

Mod 2.0 Operational on a Control Data CYBER 175 at NASA-Langley.

Includes: All of the basic program development: fully rolled-up vortices or Betz roll-up, simplified terrain modeling, WAKE plot file entry, models for propeller, helicopter, crosswind, superequilibrium turbulence, canopy, vortex penetration into canopy, and material evaporation. Also includes a stand-alone program (AGLINE) to construct the equivalent Gaussian distribution.

Graphics: Tektronix 4025 and 401X terminals using NASA-Langley graphics software.

Mod 3.0 Operational on a Univac 1108 at Ft. Collins (USDA Forest Service).

Improvements: Helicopter modeling with transition to rolled-up vortices; AGLINE calculations as a menu option in AGPLOT.

Additions: Discrete crosswind velocity profile; nonzero deposition height; composite deposition plots (to 16 plot files); canopy penetration by helicopter downwash; plot option to plot material diameter time history.

Graphics: DISSPLA at Ft. Collins, with appropriate subroutine calls for Tektronix terminals.

Mod 4.0 Operational on a VAX 11/785 at Dugway Proving Grounds (U. S. Army).

Improvements: Betz roll-up procedure and propeller model revised; equivalent Gaussian distribution selection criterion is a program decision involving material vertical velocity.

Additions: Models for wide body effects, simple vortex circulation decay, jet engines, multiple powerplants and parameterized evaporation; default input file option; plot option to plot material vertical velocity time history.

Graphics: CALCOMP at Dugway, with appropriate subroutine calls for the pen plotter.

Mod 5.0 Operational on a Data General MV-15000 at Missoula, and on IBM PC/XT/AT personal computers and compatibles.

Improvements:	Revised solution procedure eliminates integration step size dependence on material decay time constant.
Additions:	Axial variation added to all models; ground sprayer; continuous deposition; canopy deposition; deposition on objects.
Graphics:	GKS at Missoula; dot matrix printer output on IBM PC/XT/AT/compatibles.

Mod 6.0 Additional features to enhance program usage.

Improvements:	Added inputs specifying up to 16 drop sizes in one run, and ability to compute both "to" and "fro" aircraft directions.
Additions:	Graphics extended to include flux through a vertical plane, volume and number median diameters, and coefficient of variation as a function of lane separation.

Modifications Since Mod 5.0

1. The Program Card 0010 now contains only Maximum Time. Every AGDISP run is now considered a "full-plane" configuration.

2. Last entries on cards 0025, 0029, 0055 and 0081 no longer need to be negative to signal last card. AGDISP now reads the input file once to establish the number of entries of each card type, then reads the input file a second time to acquire these values.

3. AGDISP now internally proportions the aircraft weight on card 0023 to the biplane wings. Card 0023 should ALWAYS contain the assumed total aircraft weight.

4. The jet engine exhaust plane, propeller blade plane, nozzle axial position, and wide body nose location are all measured relative to the trailing edge of the wing or the shaft centerline of the helicopter, now with the POSITIVE direction pointing TOWARD the nose of the aircraft. Thus, in most cases AGDISP expects the jet engine exhaust plane to be downstream of the wing (a negative number), the propeller blade plane to be upstream of the wing (a positive number), and the wide body nose to be upstream of the wing (a positive number).

5. Card 0060 has been restructured. Now, the number of nozzles is entered as a single positive number; initial drop diameter is removed from this card and entered on new cards 0064; and the spray system flow rate is added to this card. Old AGDISP input files will NOT run with Mod 6.0 without revision.

6. New card 0064 gives the initial drop diameter and mass fraction of each drop size to be solved (from one to 16).

7. On card 0065, the entry of drop cutoff diameter DCUT has been changed to volatile fraction.

8. New card 0090 has been added to permit a solution for the "fro" direction (AGDISP will always solve for the "to" direction).

9. Gaussian ground deposition has been removed from the AGPLOT option list. Added options include computation of VMD and NMD, vertical flux through a specified plane, coefficient of variation and swath overlap pattern.

10. Each plot generated in AGPLOT is automatically cycled into AGVIEW on personal computers, if the user is running with AGCTRL (preferred).

11. Binary files are written in a slightly different format on personal computers, to reduce file size by ten percent.

12. New card 0027 gives the Richardson number to correct the spread of the material from the nozzles for atmospheric stability.

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Nomenclature

A	plant area fraction
C	concentration
C_C	effective canopy drag coefficient
C_D	material or aircraft drag coefficient
D	maximum body diameter
D_p	material diameter
D_t	target significant dimension
E	inertial impaction efficiency
g_i	gravity
h_c	canopy height
K	inertial impaction first parameter, Eq. (48)
M_p	material mass
M_{plane}	ground deposition
q^2	mean square turbulence level, equal to $< uu > + < vv > + < ww >$
r, R	radius
Re	Reynolds number, Eq. (8)
s	aircraft semispan
S	wing planform area
t	time
T	aircraft thrust
u_i	fluctuating local fluid velocity
U_i	mean local fluid velocity
U_∞	aircraft flight speed

ΔU	incremental axial velocity
v_*	friction velocity
v_i	fluctuating material velocity (u,v,w)
V_i	mean material velocity (U,V,W)
V_{rel}	relative velocity, equal to $\lvert U_i - V_i \rvert$
V_s	swirl velocity
w_d	downwash velocity
W_t	aircraft weight
x_i	fluctuating material position (x,y,z)
X_i	mean material position (X,Y,Z)
z_c	canopy displacement thickness
z_o	surface roughness
z_r	reference height
β	leaf capture efficiency
Γ	circulation
Γ_o	circulation at the wing centerline
δ_{ij}	Kroneker delta function
$\Delta\Theta$	wet bulb temperature depression
Θ	temperature
κ	von Karman constant
Λ	macroscale length
μ	forward advance ratio
ν_{air}	kinematic viscosity of air

ρ_{air}	density of air
ρ_p	density of material
σ	material standard deviation
τ_e	evaporation time scale
τ_p	material relaxation time scale
τ_τ	turbulent time scale
ϕ	inertial impaction second parameter, Eq. (49)

Table of Contents

1. Introduction

The original development of AGDISP was motivated by a desire to determine how aircraft-unique wake and propulsion characteristics affect the ground deposition pattern of aerially released material. Material motion was computed by a Lagrangian formulation of the trajectory paths and the solution of ordinary differential equations. Equations for the ensemble averaged turbulent variance of the released material were developed using a locally isotropic spectral density function. Idealized flow field models were constructed for aircraft vortex wakes, helicopter flow fields, propeller swirl, terrain, crosswind, plant canopy and superequilibrium turbulence. The result of this work was the Mod 2.0 version of AGDISP as reported in Bilanin and Teske 1984 and Teske 1984.

Enhancements to this program include additional models for wide body effects, jet engines and vortex circulation decay. Refinements to the program, notably to the helicopter model and graphical presentation of results, proceeded as the program was made operational at additional computer sites (Mod 3.0, Teske 1985; Mod 4.0, Teske 1986; Mod 5.0, Teske 1988d, 1989b and 1990a). This document contains the latest model developments compiled in Mod 6.0, operational on the Data General computer at Missoula and IBM PC/XT/AT compatibles.

This manual is organized as follows. Section 2 summarizes equation development and the models currently available in AGDISP. Section 3 discusses the operation of AGDISP and includes a listing of program restrictions, error and warning messages that may arise. Section 4 explains the input data options to AGDISP, and Section 5 explains the operation of the companion plotting package AGPLOT. Section 6 examines the test cases used to exercise AGDISP. Section 7 reviews the usage of AGDISP and AGPLOT on mainframe computer systems, while Section 8 reviews their usage on personal computers (including the use of AGEDIT, AGVIEW and AGCTRL). Section 9 highlights the selection of background turbulence level. The Appendices contain an explanation of each subroutine in the program, flowcharts of program structure and a listing of common variables.

2. Summary of Models

A Lagrangian approach is used to develop the equations of motion of discrete material released from aircraft, with the resulting set of ordinary differential equations solved exactly from step to step. The formulation of the material equations, particularly the ensemble averaged approach used to develop turbulent properties of the material-atmospheric interaction, is detailed in Bilanin and Teske 1984. This section of the User Manual examines those variables and nomenclature that are a part of the AGDISP program.

The aircraft is assumed to be in level flight near the surface, releasing material into a (y,z) plane normal to the flight direction, -x, as shown in Figure 2-1. AGDISP solves for the transport of this material within this plane, until it deposits upon the surface or is carried aloft by wind or vortical motions. Accuracy of predictions requires an accurate description of background environment (mean winds and turbulence). The need for accuracy must, however, be balanced by the requirement for computational speed and ease of calculation. Simulations need to be performed simply and repeatedly under a variety of background conditions, with minimum computer demands and setup requirements. When the need is justified, the solution for the background environment may be found by a larger, more detailed program, such as the UNIWAKE program discussed in Bilanin and Teske 1988 and Teske 1988a. The mean velocity and turbulence profiles predicted by such programs may then be read by AGDISP to predict released material behavior. As an alternate approach AGDISP has been fitted with extensive simplified flow field options to permit the prediction of material motion in a wide range of idealized background conditions. These models are summarized in this section of the User Manual.

The released material is assumed to be spherically shaped. The material flight path as a function of time after release is computed as the locations (X,Y,Z) for all material included in the simulation. The material velocity is denoted by (U,V,W). The material is affected by the background environment; however, the environment is assumed to be unaffected by the presence of the material. The interaction of the material with the turbulence in the environment creates turbulent correlation functions for the position and velocity, $< yv >$ and $< zw >$; for the velocity variance, $< vv >$ and $< ww >$; and for the position variance, $< yy >$ and $< zz >$. The square root of these last two variables gives the horizontal and vertical standard deviations of the material motion about the mean described by Y and Z.

MATERIAL EQUATIONS OF MOTION

In AGDISP the released material is assumed to be influenced by two forces: weight and aerodynamic drag. The governing equations are derived in Bilanin and Teske 1984 and repeated here for completeness:

Mean Equations:

$$\frac{d^2X_i}{dt^2} = (U_i - V_i)\left[\frac{1}{\tau_p}\right] + g_i \tag{1}$$

$$\frac{dX_i}{dt} = V_i \tag{2}$$

Turbulent Correlations:

$$\frac{d}{dt} < x_i x_i > = 2 < x_i v_i > \tag{3}$$

$$\frac{d}{dt} < x_i v_i > = \left(< x_i u_i > - < x_i v_i > \right) \left[\frac{1}{\tau_p} \right] + < v_i v_i > \tag{4}$$

$$\frac{d}{dt} < v_i v_i > = 2 \left(< u_i v_i > - < v_i v_i > \right) \left[\frac{1}{\tau_p} \right] \tag{5}$$

In Eqs. (1) - (5), X_i, V_i and U_i are the ensemble averaged i<u>th</u> components of material position, material velocity and local fluid velocity, respectively, while x_i, v_i and u_i are the fluctuating i<u>th</u> components of material position, material velocity and local fluid velocity, respectively.

Inherent in the material equations is a relaxation time τ_p which is essentially the e-folding time for the released material to come up to speed with the local fluid velocity (for V_i to approach and equal U_i). The relaxation time is defined as

$$\tau_p = \frac{4}{3} \frac{D_p \, \rho_p}{C_D \, V_{rel} \, \rho_{air}} \tag{6}$$

where D_p is the diameter of the material, ρ_p is its density, ρ_{air} is the density of air, V_{rel} is the relative velocity between the material and the local background, and C_D is the material drag coefficient. The semiempirical formula for C_D (Langmuir and Blodgett 1946) is

$$C_D = \frac{24}{Re} \left(1 + 0.197 \, Re^{0.63} + 0.00026 \, Re^{1.38} \right) \tag{7}$$

where Re is the Reynolds number defined as

$$Re = \frac{D_p \, V_{rel}}{\nu_{air}} \tag{8}$$

The material diameter D_p is affected by evaporation (Trayford and Welch 1977) as

$$\frac{1}{D_p} \frac{d \, D_p}{dt} = - \frac{1}{2 \, \tau_e \left(1 - \frac{t}{\tau_e} \right)} \tag{9}$$

where τ_e is the e-folding evaporation time

$$\tau_e = \frac{D_p^2}{\beta \, \Delta\Theta} \tag{10}$$

and $\Delta\Theta$ is the wet bulb depression in deg C, with β defined as

$$\beta = 84.76 \left[1 + 0.27 \, Re^{1/2} \right] m^2/sec - deg \, C \tag{11}$$

In a recent series of tests (Dennison and Wedding 1984), the evaporation model described by Eq. (9) was compared with wind tunnel results. A typical comparison is shown in Figure 2-2, illustrating favorable agreement with the test data.

Equations (1) - (5) cannot be solved without specifying relationships for the quantities $< x_i u_i >$ and $< u_i v_i >$, the correlations of the material position and material velocity fluctuations, respectively, with the local fluid velocity fluctuation. These expressions are developed by integrating their ensemble averaged frequency spectra using a spectral density function for transverse velocity fluctuations in isotropic turbulence (von Karman and Howarth 1938). The results (detailed in Bilanin and Teske 1984) give

$$< x_i u_i > = \frac{q^2}{3} \left[-\tau_p K + \frac{\tau_\tau}{2} \right] \tag{12}$$

$$< u_i v_i > = \frac{q^2}{3} K \tag{13}$$

with

$$K = \frac{1}{2} \frac{\left[3 - \left(\frac{\tau_p}{\tau_\tau} \right)^2 \right] \left[1 - \frac{\tau_p}{\tau_\tau} \right] + \left(\frac{\tau_p}{\tau_\tau} \right)^2 - 1}{\left[1 - \left(\frac{\tau_p}{\tau_\tau} \right)^2 \right]^2} \tag{14}$$

where τ_τ is the travel time of the material through a turbulent eddy of scale Λ, adjusted for the passive tracer limit

$$\tau_\tau = \frac{\Lambda}{V_{rel} + \frac{3}{8} q} \tag{15}$$

The quantity q^2 is the mean square turbulence level in the fluid.

With the position and velocity information available for all released material at any time during the simulation, Eqs. (1) - (5) may be integrated exactly for the solution at the next time step (Teske 1988d). This step result serves as initial conditions for the next step integration, etc., through the entire simulation. The assumption that the background conditions U_i, $< x_i u_i >$ and $< u_i v_i >$ are constant across a time step permits solution of Eqs. (1) - (5) unrestricted by the size of the released material. Computational solution times are

reduced significantly, and heretofore unsolvable material diameters (including the passive tracer limit, $D_p = 0$) are tracked by the equations.

FLOW FIELD MODELING

The behavior of the released material is intimately connected to the local background mean velocity U_i and turbulence field q^2 through which the material is transported. AGDISP has been configured to accept user specified mean velocity and turbulence flow fields in neutral atmospheres, but also contains a number of simplified models for the flow field velocity and turbulence levels behind aircraft. These models are summarized below.

Fixed-Wing Rolled Up Tip Vortices

When an aircraft flies at a constant altitude, the aerodynamic lift generated by the lifting surfaces of the aircraft equals the aircraft weight. The majority of the lift is carried by the wings, and generates one or more pairs of swirling masses of air (called vortices) downstream of the aircraft. If the roll-up of this trailing vorticity can be approximated as occurring immediately downstream of the wing, then the mean velocity field that results may be simply characterized by the aircraft semispan s, circulation Γ and load distribution (Figure 2-3).

Fixed-Wing Betz Roll Up

When the wing loading cannot be approximated by a single vortex pair, or the aircraft is flying sufficiently fast that roll-up cannot be assumed to occur immediately downstream of the wing, then the Betz methodology (Betz 1933) may be employed. The solution procedure (documented in Bilanin and Donaldson 1975) relates the swirling velocity distribution in the vortices to the details of the wing spanwise load distribution by assuming that angular momentum is approximately conserved. For complicated wing planform shapes, a vortex lattice analysis must be invoked to generate the wing spanwise load distribution (Margason and Lamar 1971). In a simulation involving the Betz methodology, the vortex sheet rolls into the vortex as a function of time. Thus, the unrolled sheet will contribute to the ambient fluid velocity during the roll-up process.

Vortex Circulation Decay

The flow field generated by a simply loaded wing includes four vortices: the two from either wing tip, and image vortices below the surface (Figure 2-4). The local ambient velocity is the vector sum of the four swirl velocity components, each written as

$$V_s = \frac{\Gamma}{2\pi r} \qquad (16)$$

with its direction measured perpendicular to a line connecting each vortex centroid and the observation point. The observation point might be a material position or the location of another vortex (which also moves because of the other vortices present in the flow). An inviscid vortex of constant positive circulation strength Γ_o descends toward the surface while increasing the separation distance between its companion vortex.

In the atmosphere, turbulence acts to decay the vortex strength. A simple decay model, developed in Donaldson and Bilanin 1975, results in a vortex decay of the form

$$\Gamma = \Gamma_o \exp\left(- \frac{Bqt}{s} \right) \tag{17}$$

For vortices out of ground effect, a typical value for B = 0.41; while a detailed examination of Program WIND data in ground effect (Teske 1988b and Bilanin et al. 1989b) gives Bq = 0.56 m/sec.

Helicopter In Forward Flight

The helicopter model includes both hover downwash and the tip vortex pair by partitioning the helicopter weight between the two effects as a function of time. The hover downwash model is taken from actuator disk theory for a propeller and may be written as

$$F\, W_t = 2\, \pi\, \rho_{air}\, R^2\, w_d^2 \tag{18}$$

while the strength of the vortex pair may be found from

$$(1 - F)\, W_t = 2\, \rho_{air}\, R\, U_\infty\, \Gamma \tag{19}$$

where W_t is the helicopter weight, w_d is the downwash at the rotor plane, R is the radius of the rotor and Γ is the tip circulation strength. The function F is determined by the expression

$$F = \exp\left(- \frac{k\, \mu\, \Gamma_o\, t}{\sigma\, \pi\, R^2} \right) \tag{20}$$

where μ is the forward advance ratio, σ is the solidity and Γ_o is the solution to Eq. (19) for F = 0. The constant k relates helicopter roll-up (around a circumference at the blade tip) to fixed-wing roll-up. Predicted results from a helicopter wake model (Bliss, Teske and Quackenbush 1984) suggest that the downwash flow field quickly transitions (within two blade revolutions) into a vortex pair. A typical value for k = 7. Comparisons of Eqs. (18) - (20) with detailed helicopter wake predictions give surprisingly good results (Teske 1989a).

The tip vortices influence the flow field everywhere, while the downwash affects only the spreading region beneath the rotor and the fluid column directly above the rotor. Within the boundaries of the rotor blade and the dividing streamline (Figure 2-5), the

velocity is assumed to follow a stagnation point flow, while the vortex pair created by the helicopter is assumed to follow the dividing streamline.

Material released ahead of the helicopter (spray boom forward) is assumed to encounter a streamline pattern similar to flow around a circular cylinder (the actuator disk downwash, Kuethe and Schetzer 1964)

$$U = U_\infty \left(1 - \frac{R^2}{r^2} + \frac{2 R^2 y^2}{r^4} \right) \tag{21}$$

$$V = - \frac{2 U_\infty R^2 x y}{r^4} \tag{22}$$

until the material crosses the plane of the helicopter shaft centerline.

Jet Engine

The jet engine exhaust is modeled as a turbulent circular jet using the similarity analysis reported in Schlicting 1968. The results give the axial and radial velocities as

$$u_{axial} = \frac{3}{8\pi} \frac{\sqrt{\frac{T}{\rho_{air}}}}{\varepsilon x} \frac{1}{\left(1 + \frac{\eta^2}{4}\right)^2} \tag{23}$$

$$v_{radial} = \frac{1}{4}\sqrt{\frac{3}{\pi}} \frac{\sqrt{\frac{T}{\rho_{air}}}}{x} \frac{\left(\eta - \frac{\eta^3}{4}\right)}{\left(1 + \frac{\eta^2}{4}\right)^2} \tag{24}$$

with

$$\eta = \frac{1}{4}\sqrt{\frac{3}{\pi}} \frac{\sqrt{\frac{T}{\rho_{air}}}}{\varepsilon} \frac{r}{x} \tag{25}$$

$$\varepsilon = 0.0161 \sqrt{\frac{T}{\rho_{air}}} \tag{26}$$

where T is the jet thrust and x is the downstream distance (corrected for the virtual origin). The radial velocity v_{radial} becomes part of the local fluid velocity, while the axial velocity u_{axial} is also used to evaluate the turbulence level

$$q^2 = 0.2034\, u_{axial}^2 \tag{27}$$

where the proportionality constant is determined from the centerline decay of turbulence in a free jet (Wygnanski and Fiedler 1969).

Propeller

The propeller is modeled as an actuator disk, where the incremental velocity ΔU over the flight speed U_∞ is related to the actual thrust produced by the propeller

$$T = 2\,\pi\,\rho_{air}\,R^2\,\Delta U\left(U_\infty + \Delta U\right) \tag{28}$$

where R is the radius of the propeller. In steady flight the thrust equals the aircraft drag, so that

$$T = C_D\,\frac{1}{2}\,\rho_{air}\,U_\infty^2\,S \tag{29}$$

where S is the wing planform area and C_D is the aircraft drag coefficient. Combining Eqs. (28) and (29) to eliminate thrust, we obtain

$$\frac{\Delta U}{U_\infty} = \frac{1}{2}\left(-1 + \sqrt{1 + \frac{C_D\,S}{\pi\,R^2}}\right) \tag{30}$$

An alternate expression for ε, defined in Eq. (26), may be obtained from Schlicting 1968 as

$$\varepsilon = 0.0256\;R\;\Delta U \tag{31}$$

Combining this equation with Eq. (26) gives the effective thrust level for the propeller as

$$T_{eff} = 2.5275\;\rho_{air}\;R^2\;\Delta U^2 \tag{32}$$

to permit the use of Eqs. (23) - (27) for the propeller when Eq. (30) is substituted. The swirl velocity generated by the propeller is assumed to be linear in R out to its maximum value, and then zero for larger values of r. The resulting integration yields

$$V_{tip} = \frac{U_\infty^3\,C_D\,S}{\pi\,\eta\,\Omega\,R^3\left(U_\infty + \Delta U\right)} \tag{33}$$

where η is the propeller efficiency and Ω is the propeller rotation rate.

Wide Body Effects

The presence of a significant fuselage shape may generate some additional mean velocity and turbulence in the vicinity of the aircraft. For simplicity, we assume that the fuselage cross-sectional area can be modeled as an axisymmetric body shape B(x), where x is measured from the nose to the tail. Slender body theory (Ashley and Landahl 1965) then gives the additional radial velocity contribution from the changing area of

$$v_{radial} = \frac{U_\infty}{2\pi r} B'(x) \tag{34}$$

where the prime denotes a derivative in x.

The turbulence level, consistent with the axisymmetric wake created by the passage of the body, is found by matching the data in Chevray 1968 with a turbulence model (Lewellen 1977) and assuming a simple exponential decay

$$q^2 = q^2_{body} \exp\left[-\frac{1}{2}\left(\frac{r}{R_{1/2}}\right)^2\right] \tag{35}$$

where

$$q^2_{body} = 0.003\, U^2_\infty \left(\frac{x/D}{10}\right)^{-1.43} \tag{36}$$

and

$$R_{1/2} = D\left(\frac{x/D}{100}\right)^{0.33} \tag{37}$$

is the wake radius to half-width, D is equal to the maximum diameter of the body and x is corrected for the virtual origin.

Mean Crosswind

In a neutral atmospheric surface layer the horizontal velocity follows a logarithmic profile

$$V(z) = V(z_r)\frac{\ln(z/z_o)}{\ln(z_r/z_o)} \tag{38}$$

where $V(z_r)$ is the known horizontal velocity at a given altitude z_r, and z_o is the surface roughness. Surface roughness is typically taken to be 1/30<u>th</u> of the actual physical roughness height. With a linear integral scale of turbulence ($\Lambda = 0.65z$), the turbulence level becomes

$$q^2 = 0.845\left[\frac{V(z_r)}{\ln(z_r/z_o)}\right]^2 \tag{39}$$

Superequilibrium Turbulence

The detailed effects of turbulence are obtained by invoking superequilibrium turbulent transport theory (Donaldson 1973). Superequilibrium refers to the second-order closure turbulence transport model limit where the velocity correlations are able to track their equilibrium values. The nonlinear equations solved for the turbulence may be written in index form as

$$\frac{\partial U_m}{\partial x_n}\left[\delta_{im} < u_n u_j > + \delta_{mj} < u_i u_n >\right] + \frac{q}{\Lambda}\left[< u_i u_j > - \frac{1}{3}\delta_{ij} q^2\right] - \frac{\delta_{ij} q^3}{12\ \Lambda} = 0 \tag{40}$$

Since the local mean flow gradients are known, the system of equations represented by Eq. (40) may be solved exactly for $< u_i u_j >$ to determine q^2.

Plant Canopy

The canopy flow field model is an approximation of the second-order closure turbulence model discussed in Wilson and Shaw 1977. For a canopy of height h_c and plant area fraction A(z), the mean crosswind velocity above the canopy is

$$V(z) = V(z_r)\frac{\ln(z/z_c)}{\ln(z_r/z_c)} \tag{41}$$

where z_c is the displacement thickness of the canopy. Within the canopy the mean velocity and root mean square turbulence levels are assumed linear with height, in good agreement with data (Figure 2-6). The canopy alters the downwash stagnation flow below the helicopter by moving the effective surface up to z_c. Vortices entering the canopy will have decaying circulation strength of the form

$$\frac{\Gamma}{\Gamma_o} = \frac{1}{1 + \frac{\Gamma_o}{2\pi s} f(t)} \tag{42}$$

similar to the atmospheric decay effect in Eq. (17). Here the function f(t) integrates the cumulative effects of A(z) on the circulation of the vortex

$$f(t) = \frac{C_C}{\Delta h}\int_0^t dt \int_{h_c - \Delta h}^{h_c} A(z)\, f_A\, dz \tag{43}$$

where C_C is the canopy drag coefficient, Δh is the penetration depth of the vortex and f_A is the fraction of the vortex within the canopy.

Terrain

Surface slope is modeled by assuming that the ground plane remains straight but may incline left or right. Any vortices in the flow field will have a modified image vortex system to maintain zero flow through the tilted surface. The helicopter downwash model and the position of the dividing streamline are also altered. Crosswind and canopy effects are assumed to remain parallel to the tilted surface.

Ground Sprayer

A ground sprayer is modeled by eliminating the presence of the aircraft vortices and being very specific about the direction and initial velocity of each nozzle.

DEPOSITION MODELING

As material approaches the surface, deposition begins, and continues until all material is deposited (if evaporation occurs, some of the material will be left in the atmosphere to drift). Ground deposition is computed by assuming that the concentration of material around the mean may be taken as Gaussian

$$C = \frac{1}{2\pi\sigma^2} \exp\left[-\frac{(y-Y)^2}{2\sigma^2}\right] \exp\left[-\frac{(z-Z)^2}{2\sigma^2}\right] \tag{44}$$

where the released material is at position (Y,Z).

Gaussian Deposition

The material is assumed to deposit entirely at the point of surface impact. Here, Eq. (44) is integrated across all z values to give

$$M_{plane} = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left[-\frac{(y-Y)^2}{2\sigma^2}\right] \tag{45}$$

Continuous Deposition

The material is assumed to deposit incrementally as it approaches the surface, and to continue depositing at its approach rate after impact. Here, Eq. (44) is integrated from far below the surface to the material location to give

$$M_{plane} = \frac{1}{2\sqrt{2}\,\pi\,\sigma} \exp\left[-\frac{(y-Y)^2}{2\sigma^2}\right] \mathrm{erfc}\left(\frac{Z}{\sqrt{2}\,\sigma}\right) \tag{46}$$

where erfc is the complementary error function. Ground deposition is obtained by summing all incremental contributions to M_{plane} as the integration proceeds. It may be seen that for material falling vertically toward the surface, the ground deposition pattern generated by Eq. (46) will be identical to the Gaussian deposition of Eq. (45). The use of Eq. (46) leads to more realistic ground deposition distributions.

Canopy Deposition

When released material traverses a canopy, deposition on the canopy reduces the amount of material available for deposition on lower levels of the canopy or on the surface. The amount of material captured on the canopy vegetation will be directly related to the capture efficiency β and the distance traveled by the material through the canopy. Thus, at any time increment Δt, the incrementally deposited material may be found from

$$\Delta C = \beta\, C\, A(z)\, \Delta d \tag{47}$$

where Δd is the distance traveled in Δt. The quantity ΔC reduces the remaining material C available for further deposition.

Equation (47) contains A(z), the plant area fraction. This is essentially a discrete function of height through the canopy, and is the ratio of leaf area (space "occupied" by the tree) divided by the surface area allocated to each typical tree. Newton, Barnes and Barry 1987 measured the leaf area for typical almond trees in the Chico orchard. Since the trees were spaced 8.2 meters apart, the surface area for each tree becomes 68 sq. meters. The resulting plant area fraction, discrete at seven heights through the canopy, is shown in Figure 2-7.

Object Deposition

Equation (44) may also be interpreted to recover the deposition on collection devices (cards, cylinders or spheres) placed at specific locations in the wake flow field. The total amount of deposition, as computed by Eq. (44), is reduced by the efficiency of the collection device, using the formulas and empirical data found in Golovin and Putnam 1962. The impaction efficiency E (as plotted in Figure 2-8 for the three collection devices) depends on two parameters

$$K = \frac{\rho_p D_p^2 U}{9\, \rho_{air}\, \nu_{air}\, D_t} \tag{48}$$

$$\phi = \frac{9\, \rho_{air}\, D_t\, U}{\nu_{air}\, \rho_p} \tag{49}$$

The significant target dimension D_t is a typical cross-sectional distance used to characterize the size of the target (for a card, it is the smaller length; for a cylinder, it is the smaller of its diameter or length; and for a sphere, it is its diameter). Figure 2-8 demonstrates that as the target dimension increases, K decreases from Eq. (48), ϕ increases from Eq. (49), and the collection efficiency decreases (it is easier for a drop to get out of the way of a big target that significantly disturbs the flow field than a small target that does not).

Material impaction also requires a knowledge of the orientation of the target relative to the solution coordinate system. For the purposes of this analysis, a normal vector must be supplied. This (x,y,z) vector defines the direction of a perpendicular line away from the target (in the case of a cylinder or a sphere this information isolates which half of the target is to be investigated). Some typical normal vectors are given in Figure 2-9.

OVERALL MODEL VALIDATION

The first significant comparison of AGDISP predictions with data was reported in Morris et al. 1982, where the influence of rolled-up tip vortices, propeller and crosswind in the mean and variance equations were favorably compared with a series of fixed-wing experiments. Later detailed comparisons (Teske 1988c, 1989a, 1989c and Bilanin et al. 1987) demonstrate the favorable performance of AGDISP when compared with detailed field test data for both fixed-wing and helicopter experiments over a wide material size range. AGDISP models are also summarized in Bilanin et al. 1989a, and used to predict lane separation for Gypsy moth spraying in Teske, Twardus and Ekblad 1990.

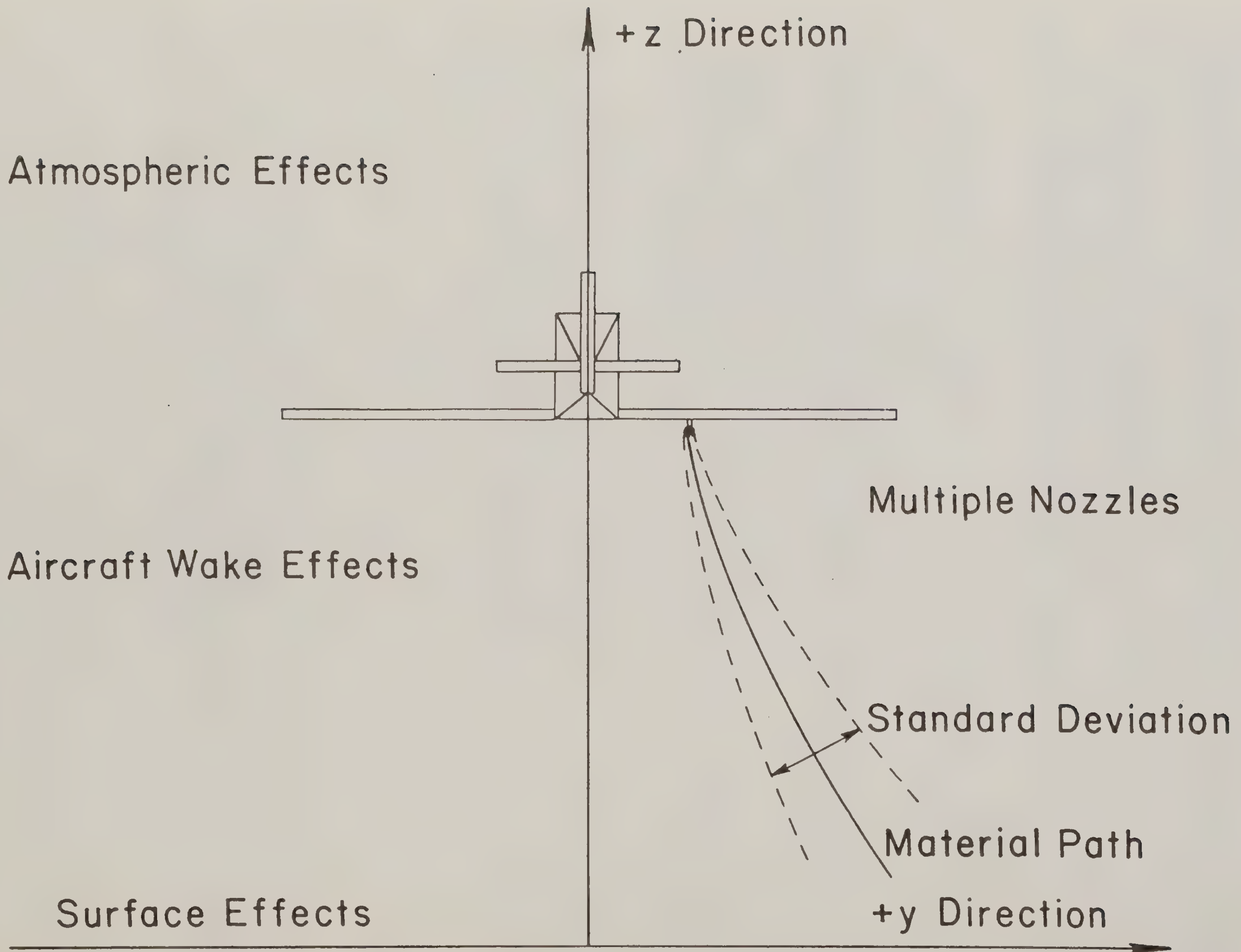

Figure 2-1 Schematic of the calculation plane of the AGDISP program. The aircraft is in level flight into the figure (the "to" direction). The positive x direction is out of the figure.

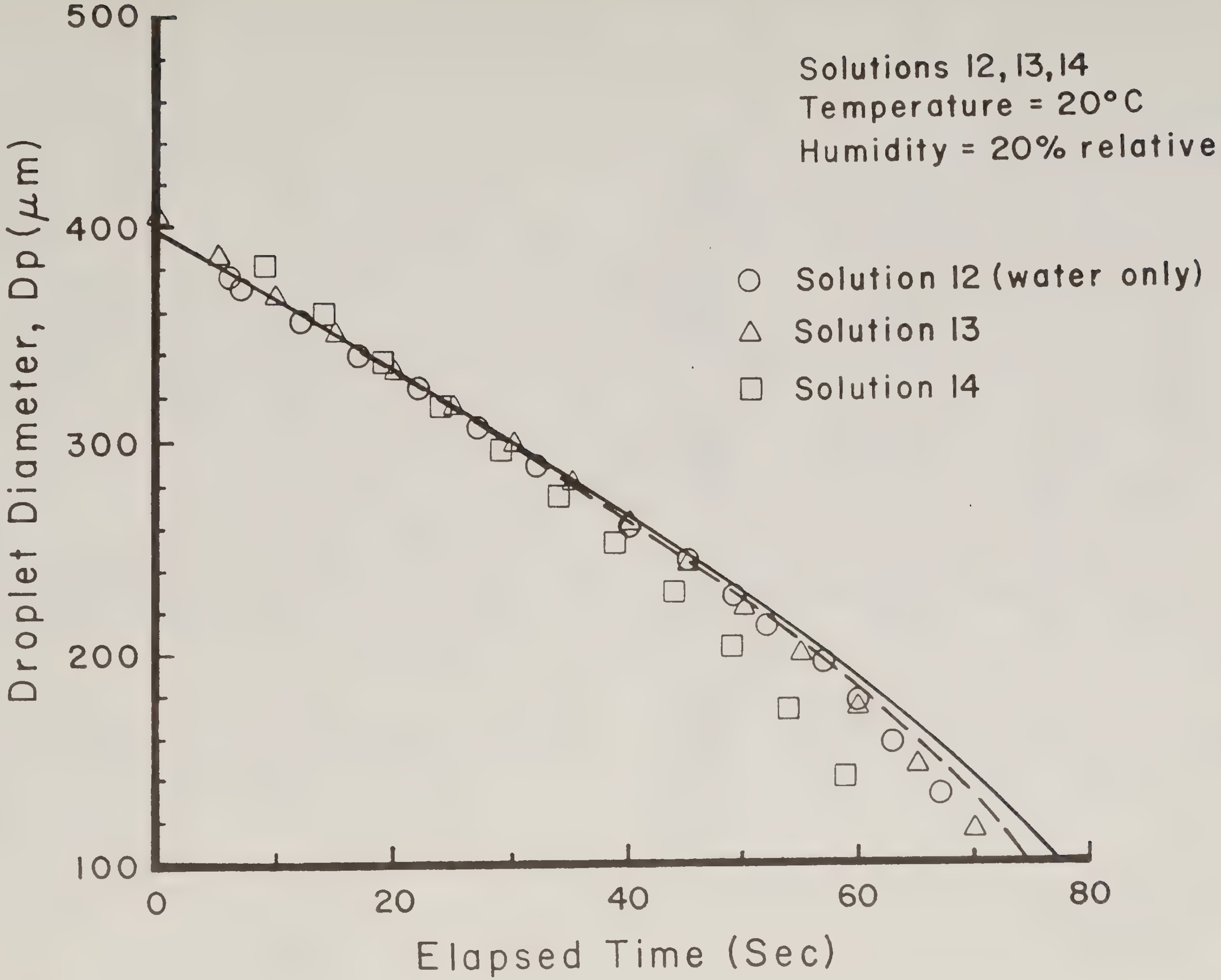

Figure 2-2 Typical prediction and measurement of drop diameter variation with time as a consequence of evaporation (Dennison and Wedding 1984).

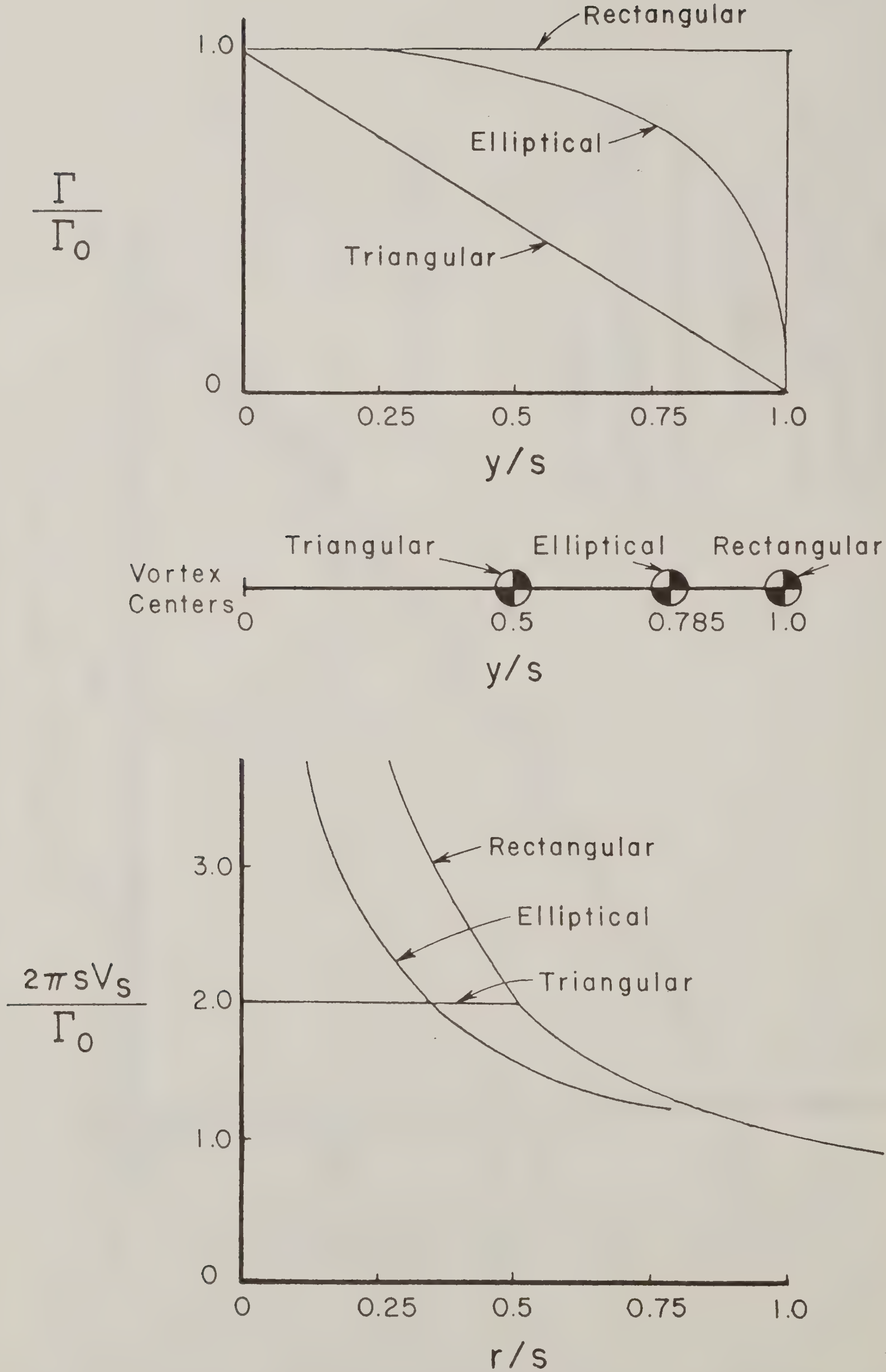

Figure 2-3 Swirl velocity distribution of a rolled-up wake as a function of spanwise load distribution and as measured from the center of the resulting vortex.

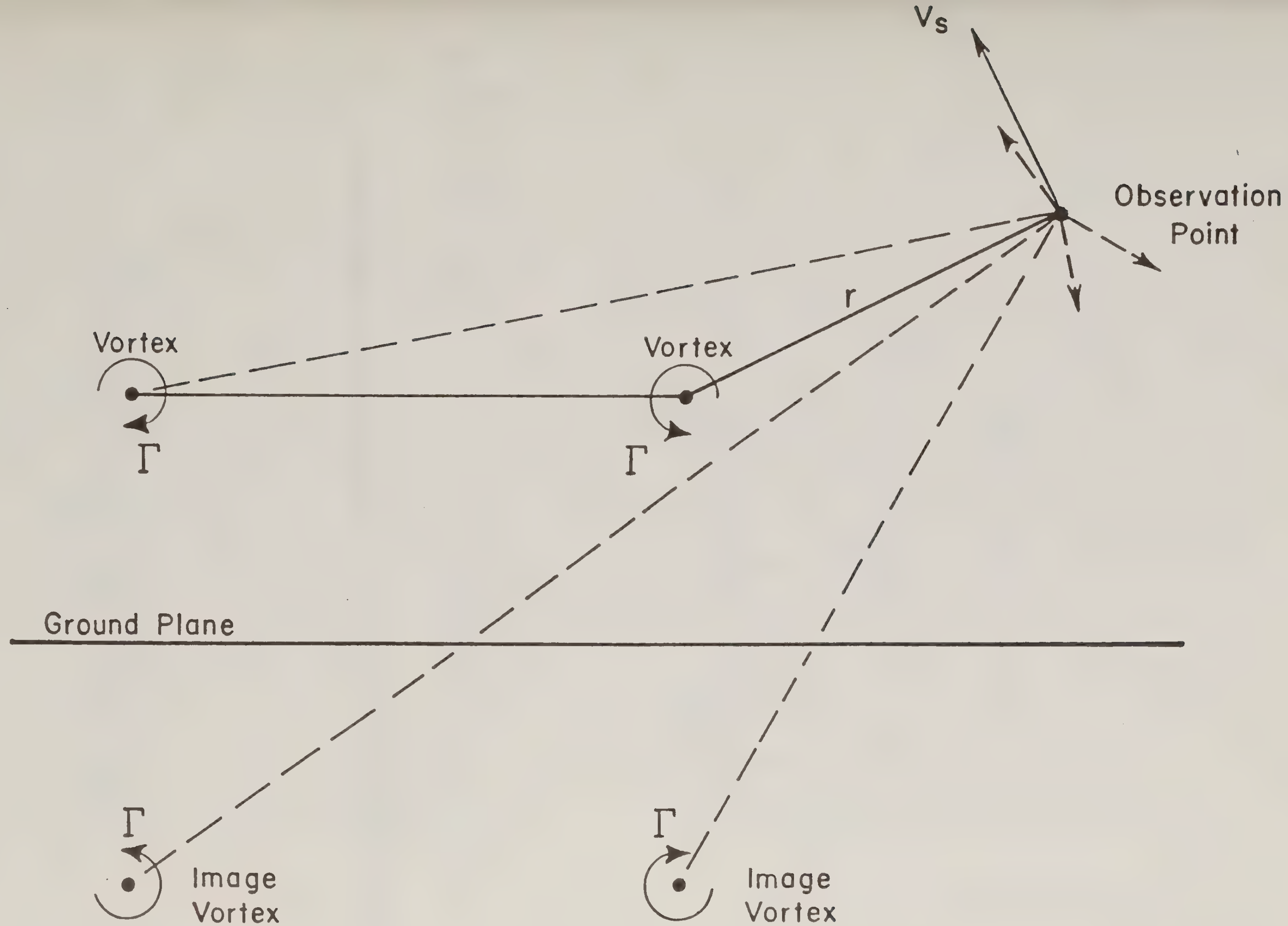

Figure 2-4 The composite velocity vector at an observation point found by summing the contributions of the aircraft vortex pair and its image pair below the surface.

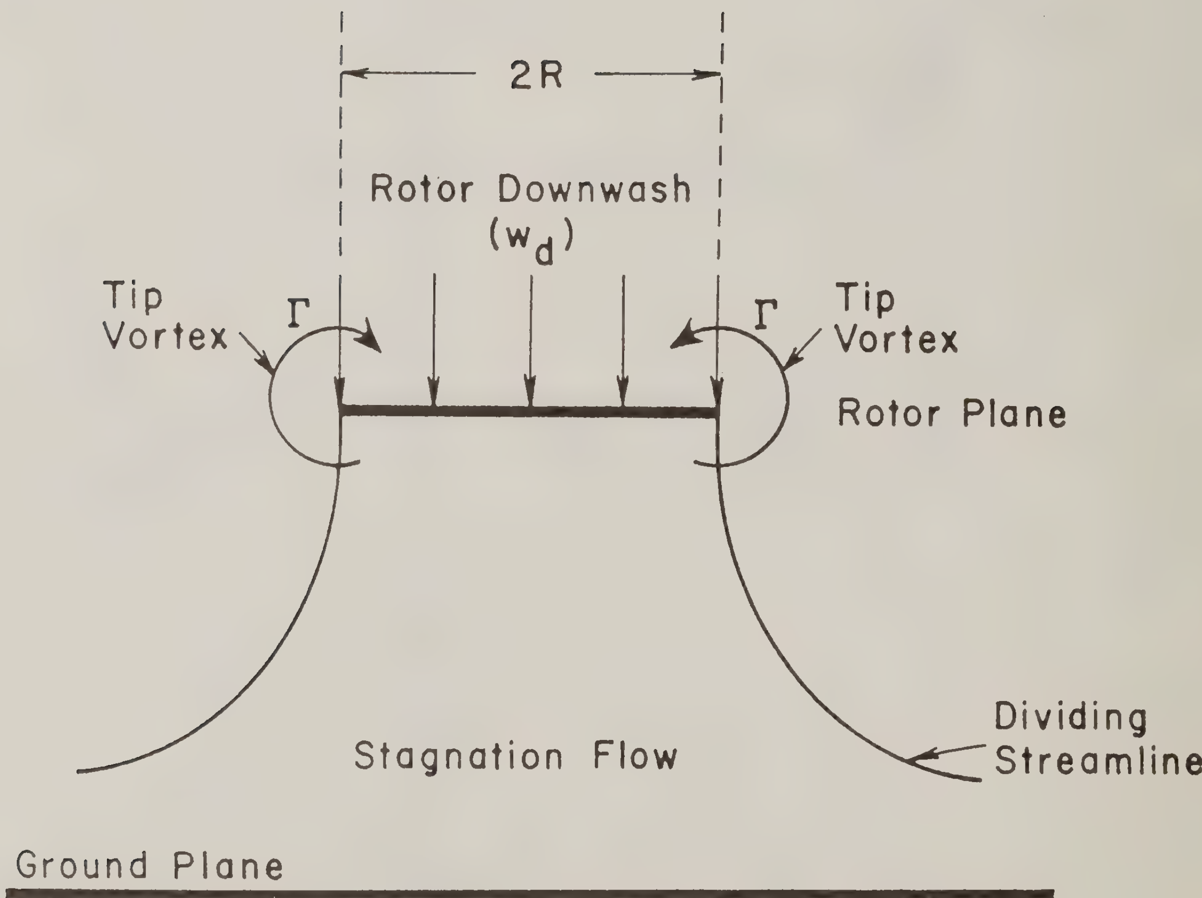

Figure 2-5 Schematic of the helicopter flow field model.

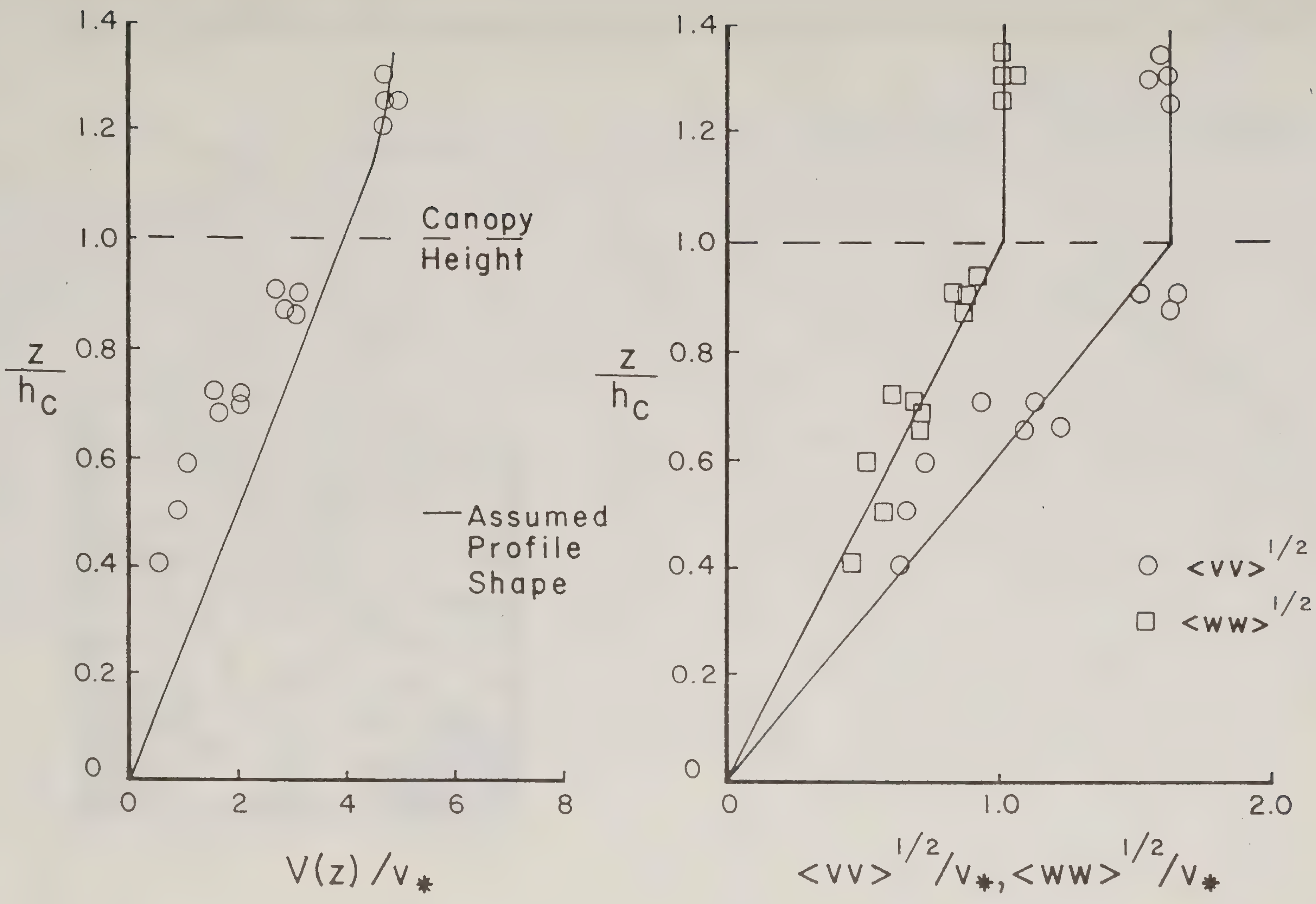

Figure 2-6 Mean wind and root mean square turbulent fluctuations in a canopy (data from Wilson and Shaw 1977), with $v_* = \kappa V(z_T) / \ln (z_T / z_C)$.

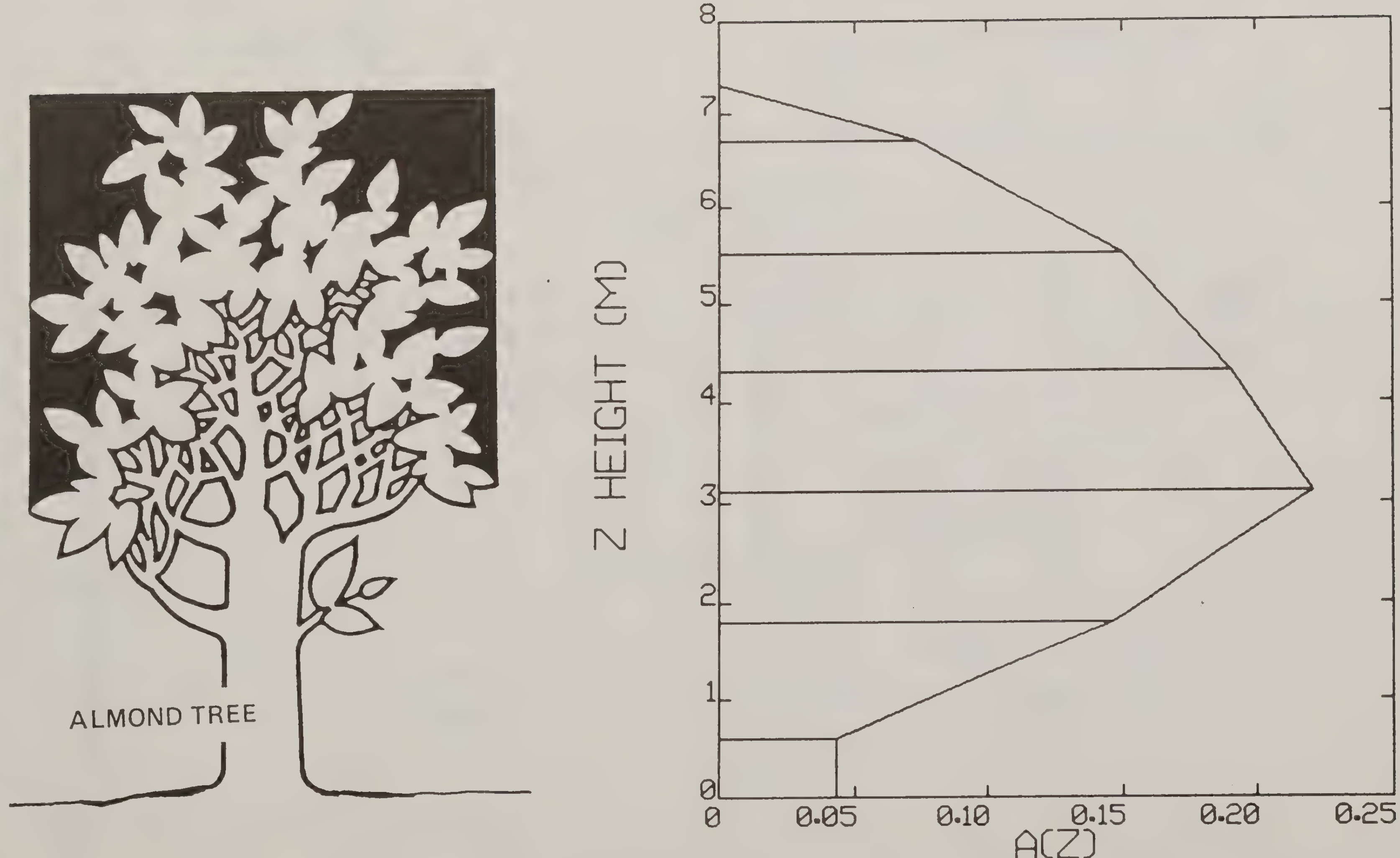

Figure 2-7 Plant area fraction as inferred from the Chico almond orchard data in Newton, Barnes and Barry 1987.

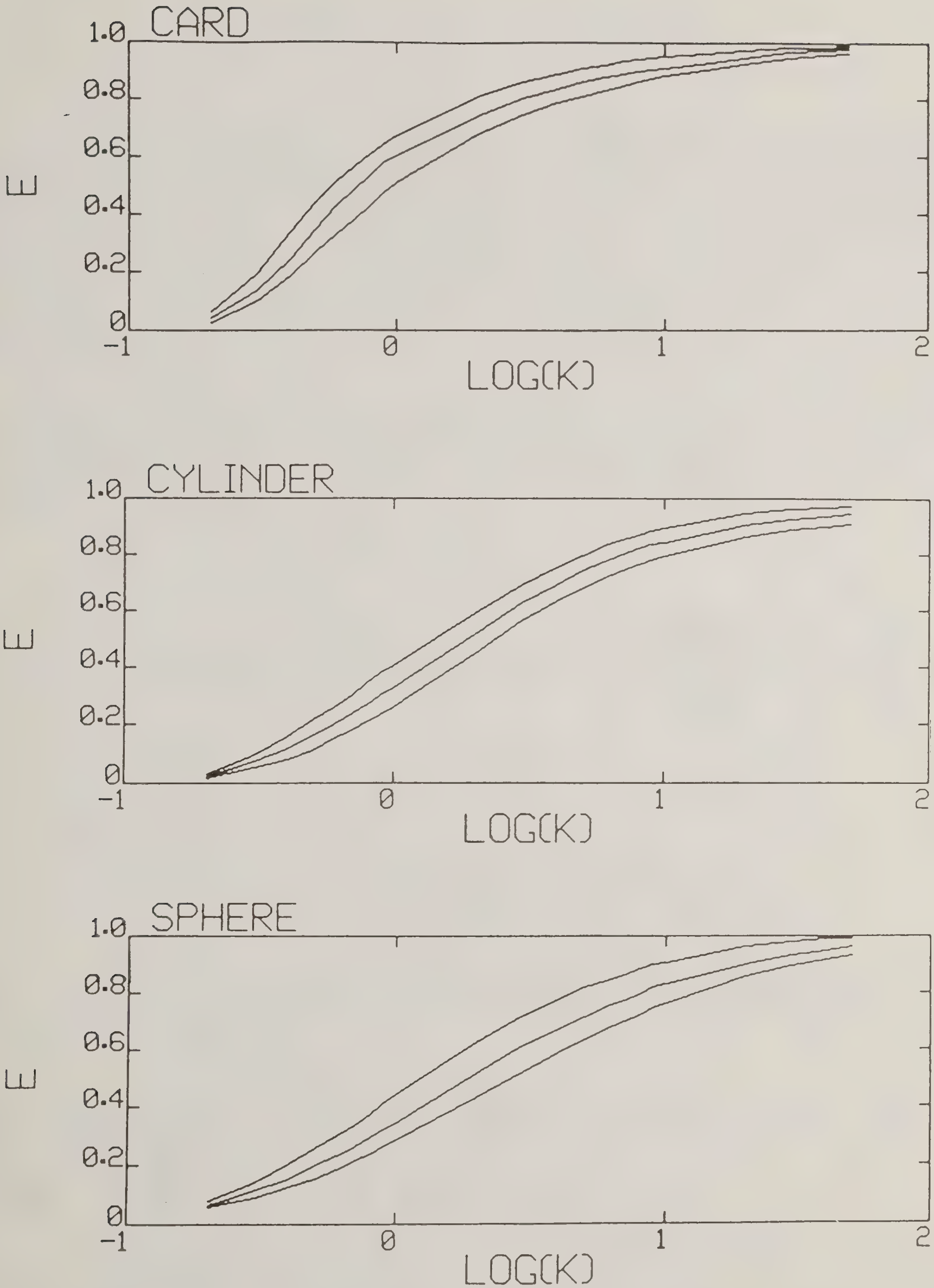

Figure 2-8 Inertial impaction efficiencies for targets discussed in Golovin and Putnam 1962. The top curve in each graph gives $\phi = 0$; the middle curve gives $\phi = 100$; and the bottom curve gives $\phi = 1000$.

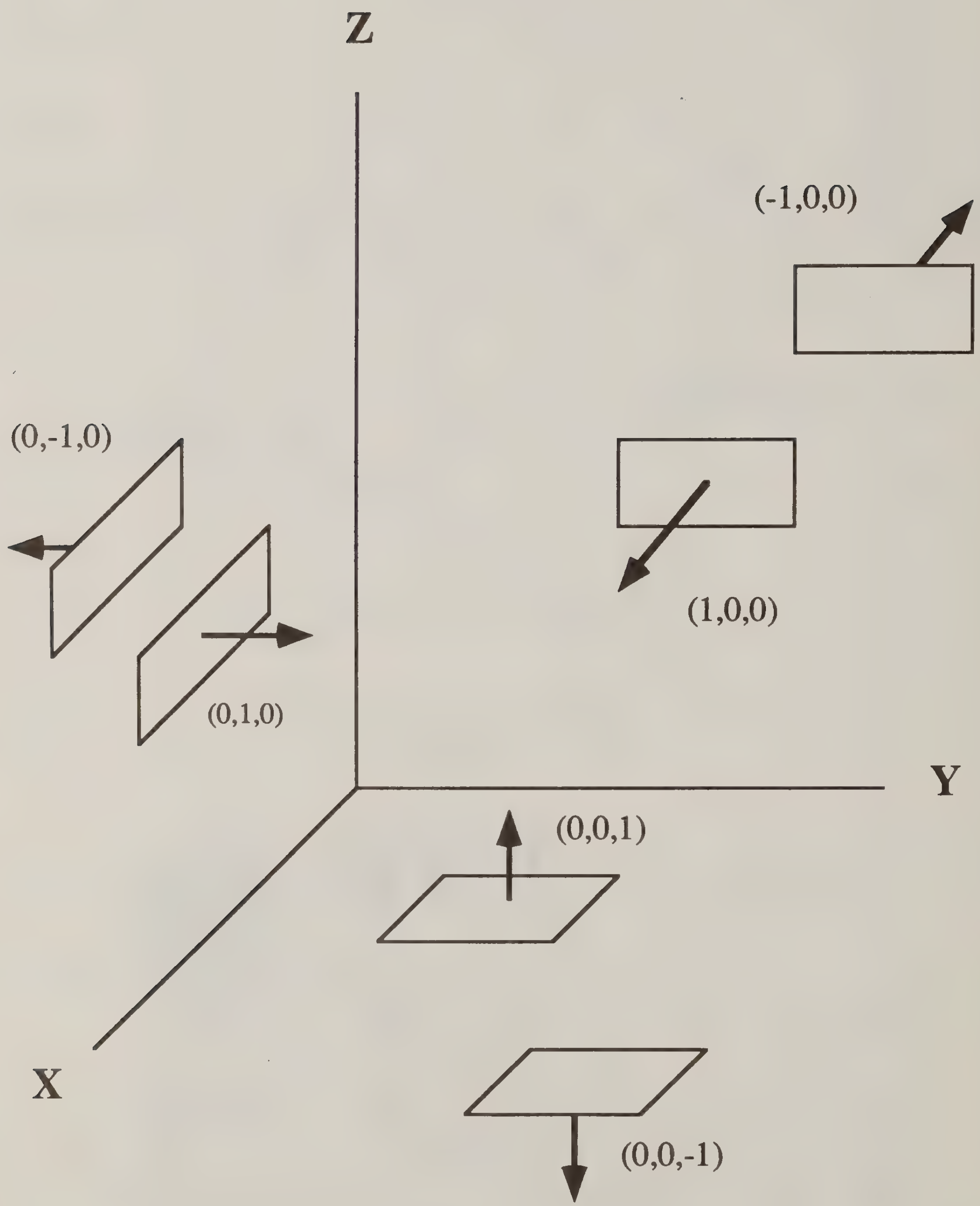

Figure 2-9 Typical target normal vectors given as (x,y,z) components.

3. Code Operation and Error Messages

AGDISP really consists of two programs: AGDISP for establishing the desired background fields and computing the material trajectories, and AGPLOT for plotting the resulting solutions. These programs are configured as interactive programs reading their needed input data from disk files and writing output to the terminal. AGDISP reads an input file of data cards (valid cards are discussed in Section 4), displays information to the screen as the run proceeds, generates printed output in a separate file, stores trajectory information in plot files for subsequent plotting, and reads WAKE plot file results from a separate data file (if invoked). AGPLOT reads the desired material plot files and interactively questions the user to supply necessary scaling data for plot construction.

AGDISP reads and processes the input data file, forcing termination of the program if errors are discovered or needed inputs are missing. Initialization follows: material locations and velocities, vortex strength, Betz roll-up, plant canopy, crosswind velocity profile, WAKE plot file. The Lagrangian equations are then integrated repeatedly until one of three termination conditions occurs:

1. Maximum simulation time is reached;
2. All of the released material has deposited on the surface; or
3. All of the material has reached the evaporation cutoff diameter and are removed from the calculation (if invoked).

Each integration step in turn includes the following:

1. Equation system solution of the equations of motion;
2. Updating the background mean velocity and turbulence fields by the WAKE plot file, Betz roll-up, vortex motion, or plant canopy; and
3. Incremental saving of the results for subsequent plotting by AGPLOT.

At the end of a run, the surface impact statistics are summarized and the deposition fraction (the mass fraction of released material that has reached the surface in the desired simulation time) is computed.

AGDISP is run from and produces data into files assigned to specific unit numbers. These files are the following:

UNIT	DESCRIPTION
4	AGDISP input file containing the appropriately constructed data entry cards.
5	Terminal input.
6	Screen output.
7	CASEFILE default file set of AGDISP input files (accessed with card 0005).

8 Binary plot files constructed by AGDISP and plotted by AGPLOT.

9 AGDISP.LIS printer listing file.

10 WAKE binary plot input file AGWAKE.BIN.

12 Binary log file constructed by AGDISP to control plotting by AGPLOT.

15 AGPLOT.PLT file constructed by AGPLOT to hold plotting instructions.

20 AGDISP.ERR and AGPLOT.ERR files generated by AGDISP and AGPLOT if an error occurs in the personal computer environment (subsequently checked by AGCTRL to detect the error).

25 AGPLOT.STP file generated by AGPLOT if a plot is to be displayed and control returned to AGPLOT in the personal computer environment.

30 Temporary file generated by AGDISP and AGPLOT for intermediate operations.

The current limits of the AGDISP code are the following:

1. All of the idealized background mean velocity and turbulence fields are for neutral environments. The inputted crosswind velocity profile will be interpreted as locally neutral. A Richardson number correction (card 0027) may be used for stable/unstable effects of turbulence on diffusion of the material from the nozzles.

2. The total number of nozzles that can be included in the simulation cannot exceed 60. The error message "Incorrect number of nozzles" will be displayed and AGDISP will terminate.

3. The Betz roll-up cannot enter more than 100 discrete circulation values along the wing. The error message "Error in Betz circulation data input" will be displayed and AGDISP will terminate.

4. The Betz roll-up procedure cannot handle more than four discrete vortices on each wing. In this case the error message "Betz will roll up more than four vortices" will be displayed and AGDISP will terminate.

5. The plant canopy input data cannot permit more than 20 discrete entries to define the canopy vertical profile shape. The error message "Error in plant area input" will be displayed and AGDISP will terminate.

6. The discrete crosswind velocity data cannot permit more than 20 entries to define the velocity profile. The error message "Error in crosswind velocity input" will be displayed and AGDISP will terminate.

7. The wide body data cannot permit more than 20 entries to define the fuselage cross-sectional area as a function of distance from the aircraft nose. The error message "Error in wide body area input" will be displayed and AGDISP will terminate.

8. The input deck to AGDISP cannot exceed 200 lines. The message "AGDISP limited to 200 input cards" will be displayed and AGDISP will terminate.

9. No more than 16 drop sizes may be entered into AGDISP for any run. The message "Error in number of drop sizes" will be displayed and AGDISP will terminate.

The list of error messages generated in AGDISP are the following:

AGDISP does not support card ...
: The input card in question is not a valid entry to AGDISP.

AGDISP limited to 200 input cards
: A maximum of 200 input cards are permitted in the AGDISP input deck.

Betz will roll up more than four vortices
: A maximum of four vortices are permitted on a wing semispan.

Card order inconsistent at card ...
: An error in input has lead AGDISP to expect a card that is not in the input deck.

Error in Betz circulation data input
: The Betz roll-up procedure must have between three and 100 discrete locations of circulation data.

Error in crosswind velocity input
: The user-supplied crosswind velocity profile must have between three and 20 discrete locations of velocity data.

Error in number of drop sizes
: The number of drop sizes must be between one and 16.

Error in number of evaporation equations
: If evaporation is parameterized, there must be as many 0066 cards as 0064 cards defining the number of drop sizes.

Error in plant area input
: The plant canopy must have between three and 20 discrete locations of plant area fraction data.

Error in wide body area input
: The wide body cross-sectional area must have between three and 20 discrete locations of area data.

Incorrect number of nozzles
: No more than 60 nozzles may be present in a simulation.

Initial condition mismatch
: Initial conditions were entered for a nonexistent nozzle.

Input card numbers not increasing

All input card identification numbers must increase in number (with the exception of card 0000).

Input does not fully initialize AGDISP

Input data cards are missing.

Insufficient data before card ...

AGDISP is not fully initialized; perhaps a card is missing from the input deck or does not have enough information on it.

Invalid CASE number

AGDISP could not locate the desired CASE number on card 0005 in CASEFILE.INP.

Premature end of WAKE plot file reached

The WAKE plot file AGWAKE.BIN ended without supplying enough profile information data to AGDISP.

WAKE plot file extrapolation

Extrapolation of data in the WAKE plot file AGWAKE.BIN first occurs; this is a warning message.

WAKE plot file (Y,Z) mesh size

The WAKE plot file AGWAKE.BIN must have between two and 16 mesh points in the y and z directions.

AGPLOT interactively plots AGDISP results on appropriate terminal screens or plotting devices. After reading the log file AGPLOT offers the current menu of plotting options available to the user (Section 5), who then determines the options to invoke. The list of error messages generated in AGPLOT are the following:

Ground encounter by equivalent gaussian

The computed equivalent Gaussian intersects the surface; this is a warning message.

Maximum scale less than minimum scale

The user-supplied scale limits are inconsistent, and AGPLOT requests re-entry of the scale data.

Maximum scale size adjusted

The user-supplied scale limits are adjusted for consistency with the supplied scale delta.

Option produces nothing to plot

The invoked option does not produce any plotable results.

Plot option not available for this LOG file

AGPLOT cannot invoke a requested option because the data needed for it was not saved in AGDISP or is not indicated in the LOG file.

Scale increment less than zero

The user-supplied scale increment was inconsistent, and AGPLOT requests re-entry of the scale data.

Too many scale divisions

The user-supplied scale data forced more than ten scale divisions, and AGPLOT requests re-entry of the scale data.

On the Data General the following error messages are also possible:

GKS_DRAW error
GKS_OPEN error
GKS_Q_WS_WIN error

GKS graphics errors on the Data General have occurred. AGPLOT operation should be reviewed and possibly repeated.

4. AGDISP Inputs

This section of the AGDISP User Manual details the input data to the program. All data entry is in free format, with number data separated by commas or blank spaces. This convenience offers ease of formatting the data but requires that every data card have all of its data values present, even if they are zero. Unless noted below as integer values, data is entered as real numbers (with decimal points). The MKS system is used throughout this section of the report, even though card 0001 permits English units entry.

All data cards begin with a four-digit identification in columns 1-4, with the rest of the data in free format in column 6 and following. The order of the cards is important and must follow ever-increasing identification numbers. AGDISP has been programmed to verify this order. In addition, certain available options are inconsistent with each other. AGDISP has been programmed to trap these inconsistencies, with the message "Card order inconsistent at card ..." followed by the offending card when an error is detected. Unsupported cards are flagged with the message "AGDISP does not support card ...", while missing data cards are flagged with "Input does not fully initialize AGDISP". With free format there exists the chance that all necessary data do not appear on the appropriate card; in this case, AGDISP will run out of data cards before it rationalizes all of its data pointers. On the other hand, because all of the data is echoed on the terminal screen, error messages are traceable in a systematic manner. A careful check should be made the first time a new case is started, and at least until the user is confident of program input requirements. Only by looking at what the program thinks is inputted will the user be able to verify that what was inputted was correct. In almost all cases, AGDISP makes no check of input validity, either signs or magnitudes. Every AGDISP run requires the entry, at least, of cards 0010, 0020, 0050, 0060 and one or more 0064.

Detailed description of the currently available data cards follows, including the special messages they invoke.

Caution: All input cards are described below, but for a specific AGDISP run, only those cards that are needed to describe the run should be included. Default entry (cards 0010, 0020, 0050, 0060 and 0064) will be sufficient to describe most runs. For example, if the run is made without evaporation, there is no reason to include card 0065.

In the descriptions that follow, Types are designated CHAR for character data, INT for integer data (no decimal point), or REAL for data with decimal point.

0000 CMNT

Variable	Type	Description (Comment Card)
CMNT	CHAR	Comment card, any number of which may be placed anywhere in the input deck.

0001 IENG

Variable	Type	Description (English Units Card)
IENG	INT	Conversion to English units. A default value of 0 (or no card) will retain the MKS units. If IENG is nonzero, AGDISP will expect weight and thrust in pounds; lengths and distances in feet; velocities in miles per hour; and temperature in degree F.

0005 ICASE

Variable	Type	Description (Casefile Card)
ICASE	INT	Case to run (or modify) found in the default case input datafile CASEFILE.INP. All of the input cards found on the case file for this case value will be added to the input runstream to build a complete input deck for AGDISP. Cards present in the input file will replace any cards of identical number found in the case file. The case file may contain any number of input files to AGDISP, each with its input information consistent with the discussion in this section. The only attribute that separates the case file decks is a first card to each deck containing the word CASE in columns 1-4 and the case number in column 6 and beyond. With card 0005 present, AGDISP will search the default case input datafile to find a match of case number; if that match is made, all of the subsequent cards up to the next CASE card will be copied to the input runstream. If a match is not made, AGDISP will print "Invalid CASE number" and terminate.

0010 TMAX

Variable	Type	Description (Program Card)
TMAX	REAL	Maximum time in seconds for the simulation to run, a time which will be shortened if the material impacts the surface or is discarded at the evaporation cutoff (with the proper input on card 0065) before TMAX is reached.

0011 NPTJ NPVX NPVL NPXX

Variable	Type	Description (Printer/Plotter Control Card)
NPTJ	INT	Modified default printing interval. Under normal operation AGDISP output is generated at appropriate intervals to the printer and the plot file. Entry of a number greater than 1 increases the printing interval (the plotting interval cannot

		be altered). Default value is 1; to turn off printing requires an entry of 0.
NPVX	INT	Invokes plot file saving of the time histories of the driving trajectories, and controls the interval of printing these time histories. The driving trajectories are those associated with the centers of vortices, the center of the propeller and the center of the helicopter rotor disk (whenever any are present in a run). Any value for this entry invokes additional plot file output, to permit subsequent plotting of the driving trajectories by AGPLOT. A number greater than 1 increases the printing interval (if nonzero, NPVX should equal NPTJ for consistent printed output). Default value is 0.
NPVL	INT	Controls whether the vertical velocities are saved on the plot file for subsequent plotting by AGPLOT. Default value is 0 (no saving of vertical velocities); any nonzero value entered on this card will force additional plot file output. Vertical velocities must be saved if the equivalent Gaussian distribution is desired.
NPXX	INT	Controls whether the mean velocities are saved on the plot file for subsequent plotting by AGPLOT. Default value is 0 (no saving of mean velocities); any nonzero value entered on this card will force additional plot file output. Mean velocities must be saved if deposition on objects is desired. In all cases, additional writes to the plot file increases its size.

0015 TA

Variable	Type	Description (Terrain Slope Angle Card)
TA	REAL	Local ground slope in degrees. A positive terrain angle raises the right side of the surface as viewed from behind the aircraft, with the origin remaining along the initial aircraft vertical centerline. The terrain is characterized by a locally straight surface so that all of the simplified flow field options in AGDISP remain available. Canopy and crosswind effects remain parallel to the tilted surface.

0020 LMVEL S DIST UO

Variable	Type	Description (Aircraft Characteristics Card)
LMVEL	INT	Mean velocity flag taking one of seven values: 5 denotes ground sprayer; 4 denotes helicopter entry;

		3 denotes an elliptically loaded, rolled-up tip vortex; 2 denotes a rectangularly loaded, rolled-up tip vortex; 1 denotes a triangularly loaded, rolled-up tip vortex; 0 denotes Betz roll-up from a given circulation, and -1 denotes WAKE plot file entry (explained under card 0050). An entry of 4 requires a 0030 card; entry of 3, 2 or 1 requires a 0023 card; and an entry of 0 requires multiple entries of 0025 cards.
S	REAL	Semispan of the aircraft in meters or feet (also the rotor radius for a helicopter).
DIST	REAL	Nominal height of the aircraft wing (or nominal height of the helicopter rotor blades) about the surface in meters or feet (this distance is the assumed nominal nozzle release height). For rolled-up tip vortices this height is the initial z coordinate of the vortex centerline. For Betz roll-up data this height is the z coordinate of the initial vortex sheet .
UO	REAL	Flight speed of the aircraft in m/sec or miles/hour.

0021 DZBP PSBP PGBP

<u>Variable</u>	<u>Type</u>	<u>Description</u> (Biplane Characteristics Card)
DZBP	REAL	Vertical distance in meters or feet from the main wing location specified on card 0020 to the second, biplane wing.
PSBP	REAL	Semispan of the biplane wing entered as a fraction of the semispan of the main wing (if the wings are equal in length this entry would be 1.0).
PGBP	REAL	Weight carried by the biplane wing entered as a fraction of the weight carried by the main wing (for equal weights this entry would by 1.0).

0023 WT

<u>Variable</u>	<u>Type</u>	<u>Description</u> (Aircraft Weight Card)
WT	REAL	Weight of the fixed-wing aircraft in Newtons or pounds, for a rolled-up tip vortex pair. AGDISP internally corrects the proportion of aircraft weight assigned to each wing in a biplane configuration (using the card 0021 data).

0025 Y G

Variable	Type	Description (Betz Wing Load Distribution Cards)
Y	REAL	Position in meters or feet measured from the wing root toward the wing tip.
G	REAL	Circulation value in m^2/sec or ft^2/sec at this location.
		After all 0025 cards are read, the Betz roll-up procedure is initialized. The ensuing roll-up invoke additional printer output summarizing the roll-up process. As the Betz roll-up continues, the material being tracked will be influenced by ever-increasing strength vortices, whose positions and strengths approach those of rolled-up vortices. AGDISP includes the effect of the unrolled-up sheets on the motion of the released material.

0027 RI

Variable	Type	Description (Richardson Number Card)
RI	REAL	Richardson number defining the stability of the atmosphere:

$$Ri = \frac{\frac{g}{\Theta}\frac{\partial \Theta}{\partial z}}{\left[\frac{\partial U}{\partial z}\right]^2}$$

For a neutral atmosphere, Ri = 0.0 (default); for stable layers, Ri may reach a value of 0.5; for unstable layers, Ri may be as or more negative than -1.0. The value of Ri modifies the background turbulence level (Bilanin, Teske and Hirsh 1978).

0028 U Z ZO CA

Variable	Type	Description (Neutral Crosswind Card)
U	REAL	Mean wind velocity in the (x,y) plane in m/sec or miles/hour.
Z	REAL	Altitude of the mean wind velocity in meters or feet (if a canopy is present, this altitude must be above the canopy).
ZO	REAL	Surface roughness height z_o in meters or feet.

CA	REAL	Direction angle in degrees <u>from which</u> the wind is blowing; i.e., for 0 deg the wind is a head wind; for 180 deg the wind is a tail wind; for 90 deg the wind is a crosswind from right to left; and for -90 deg (or 270 deg) the wind is a crosswind from left to right.

0029 Z U V

Variable	Type	Description (Discrete Crosswind Cards)
Z	REAL	Position in meters or feet beginning at the surface and increasing to the top of the computational domain.
U	REAL	Axial velocity value in m/sec or miles/hour, positive pointing downstream (head wind).
V	REAL	Crosswind velocity value in m/sec or miles/hour, positive pointing in the positive y direction. The square root of the sum of the squares of U and V recovers the total velocity magnitude at height z.
		After all 0029 cards are read, a calculation is made for the turbulence level through the velocity profile. If a canopy is present, it is assumed that the entries on cards 0029 have been modified by the user to reflect the influence of the canopy on the crosswind velocity profile and its subsequent turbulence calculation.

0030 WT BDOT

Variable	Type	Description (Helicopter Card)
WT	REAL	Weight of the helicopter in Newtons or pounds.
BDOT	REAL	Blade rotation rate in rpm.
		The helicopter is idealized as a dynamic transition from a rotor downwash field to a rectangularly loaded, rolled-up vortex pair.

0035 THT RPRP DZ XPRP

Variable	Type	Description (Jet Engine Card)
THT	REAL	Thrust of the engine in Newtons or pounds.
RPRP	REAL	Exit radius of the engine in meters or feet.
DZ	REAL	Incremental distance in meters or feet of the engine centerline above or below the nominal release height given on card 0020 (the jet engine is assumed to be at the aircraft

		centerline, y = 0). The placement of the jet engine is superseded by the presence of card 0045.
XPRP	REAL	Axial distance from the trailing edge of the wing to the exit plane of the jet engine in meters or feet, where positive is measured upstream.

0040 CD AS ETA TDOT RPRP DZ XPRP

Variable	Type	Description (Propeller Card)
CD	REAL	Drag coefficient of the aircraft (typically 0.1).
AS	REAL	Airplane planform area in m^2 or ft^2.
ETA	REAL	Propeller efficiency (typically 0.8 to 0.9).
TDOT	REAL	Shaft rpm.
RPRP	REAL	Propeller blade radius in meters or feet.
DZ	REAL	Incremental distance in meters or feet of the shaft centerline above or below the nominal release height given on card 0020 (the propeller is assumed to be at the airplane centerline, y = 0). The placement of the propeller is superseded by the presence of card 0045.
XPRP	REAL	Axial distance from the trailing edge of the wing to the propeller blade plane in meters or feet, where positive is measured upstream.

0045 NPRP (TV(N), N = 1 TO NPRP)

Variable	Type	Description (Powerplant Placement Card)
NPRP	INT	Number of engines (1 to 4, although 1 is the default on cards 0035 and 0040).
TV	REAL	An equal number of dimensions following the pattern for one engine: incremental distance (meters or feet) at the aircraft centerline above or below the nominal height; for two engines: positive horizontal position (meters or feet) of the engine from the aircraft centerline; and incremental distance (meters or feet) of the engine above or below the nominal height (the other engine is symmetrically positioned);

for three engines:

incremental distance (meters or feet) at the aircraft centerline above or below the nominal height for the engine at the aircraft centerline;
positive horizontal position (meters or feet) of the second engine from the aircraft centerline; and
incremental distance (meters or feet) of the engine above or below the nominal height (the third engine is symmetrically positioned);

for four engines:

positive horizontal position (meters or feet) of the first engine (closer to the aircraft centerline) from the aircraft centerline;
incremental distance (meters or feet) of the engine above or below the nominal height (the second engine is symmetrically positioned);
positive horizontal position (meters or feet) of the third engine (farther from the aircraft centerline) from the aircraft centerline; and
incremental distance (meters or feet) of the engine above or below the nominal height (the fourth engine is symmetrically positioned).

0047 (IPRPS(N), N = 1 TO NPRP)

Variable	Type	Description (Propeller Rotation Card)
IPRPS	INT	Up to four integers (depending on the number of engines in the simulation). Propellers are numbered from the left wingtip to the right, looking upstream; the integer is 1 if the propeller rotates clockwise, and -1 if the propeller rotates counterclockwise. Defaults are as follows:

1 propeller	1			
2 propellers	1	-1		
3 propellers	1	1	-1	
4 propellers	1	1	-1	-1

0050 LQQSE QQMX

Variable	Type	Description (Turbulence Card)
LQQSE	INT	Turbulence flag carrying one of the following values:

- 1 invokes superequilibrium turbulence;
- 0 assumes a fixed value of turbulence given on this card; and
- -1 specifies the attached WAKE plot file (invoked with a -1 entry on card 0020).

QQMX	REAL	Maximum value of the background turbulence q^2 in m^2/sec^2 or ft^2/sec^2 (this value is incremented by the presence of a crosswind). The turbulence level generated by a crosswind flow field is generally sufficient to represent the ambient turbulence level (the input on card 0050 would then be 0.0 for q^2). However, in some cases, it may be necessary to augment this value for specific local atmospheric conditions. A short guide to the selection of appropriate background turbulence levels is offered in Section 9.

With no crosswind, QQMX must be nonzero on this card.

A -1 on card 0020 invokes the WAKE plot file and must be accompanied by a -1 on this card. The WAKE plot file (AGWAKE.BIN) contains the crossplane velocities V and W, and the turbulence q^2.

The sequential binary WAKE plot file is constructed as follows (with FORM='BINARY' on personal computers):

<u>Record 1:</u> The number of y (or horizontal) mesh points and z (or vertical) mesh points in the plot file (two integers). The code restricts both of these entries to 16 or less; larger values invoke the error "WAKE plot file (Y,Z) mesh size";

<u>Record 2:</u> The y mesh values in meters;

<u>Record 3:</u> The z mesh values in meters;

<u>Record 4</u> and following: The profile data follows, with each time slot repeating the same pattern. It begins with a single record which is the time saved in seconds. The data for each variable on the file (specified in the order V, W, q^2) follows, by giving all of the y values of V at the first z position, then all of the y values of V at the second z position, on to the last z position; then on to all of the y values of W at the first z position, etc., until the values of all of the variables at all of the y and z positions have been given. The next time value follows, repeated to the end of the plot file. Velocities are in m/sec and turbulence in m^2/sec^2. The warning message "WAKE plot file extrapolation" is output the <u>first</u> time spatial extrapolation must be used by the AGDISP code during interpolation for the variables contained on the WAKE plot file. For times beyond the entries in the WAKE plot file, the spatial profiles nearest in time to the time being solved in AGDISP will be used.

Before integrating the equations, AGDISP reads the entire WAKE plot file through to its end. If the file is constructed incorrectly, the error "Premature end of

WAKE plot file reached" is invoked, and AGDISP terminates.

0055 Z AA

Variable	Type	Description (Canopy Cards)
Z	REAL	Position in meters or feet beginning at the surface and increasing to the top of the canopy.
AA	REAL	Plant area fraction corresponding to the z position.
		After all 0055 cards are read, the canopy calculation is initialized, computing the displacement thickness of the canopy and forcing modification to the crosswind velocity and turbulence within the canopy. During the AGDISP run, trajectories of the aircraft vortices will be altered upon entering the canopy, and the position of the helicopter dividing streamline will also be changed.

0056 CEFF

Variable	Type	Description (Canopy Collection Efficiency Card)
CEFF	REAL	Canopy capture efficiency β (Eq. 47). Default value is 1.

0060 NVAR DZ XO DENF FLOW

Variable	Type	Description (Nozzle Card)
NVAR	INT	Number of nozzles in the entire calculation (this number may be odd or even). Unless followed by cards 0061, AGDISP will position the nozzles uniformly along the wing (or rotor centerline) between minus and plus three-fourths of the semispan (or rotor radius), numbered from left to right from behind the aircraft.
DZ	REAL	Vertical position in meters or feet off-setting the nozzles from the height of the wing (or rotor plane) given on card 0020.
XO	REAL	Nominal axial position of the nozzles relative to the trailing edge of the wing (or the shaft centerline of the helicopter) in meters or feet, positive measured upstream.
DENF	REAL	Specific gravity of the released material.
FLOW	REAL	Flow rate from the spray system in gallons/minute.

0061 Y Z

Variable	Type	Description (Discrete Nozzle Location Cards)
Y	REAL	Y value in meters or feet along the spray boom.
Z	REAL	Vertical position in meters or feet off-setting the release point from the height of the wing (or rotor plane) given on card 0020. The vertical position offset on card 0060 is disregarded. Discrete nozzle locations permit fine tuning of nozzle locations, and are necessary if nozzles are not uniformly distributed along the wing or if the spray boom is not parallel to the surface. The number of 0061 cards must equal the number of nozzles NVAR on card 0060.

0062 N U V W XS VS

Variable	Type	Description (Nozzle Initial Condition Cards)
N	INT	Nozzle number, recorded from the left nozzle position.
U	REAL	Initial axial velocity in m/sec or miles/hour at nozzle number N, positive measured downstream.
V	REAL	Initial horizontal velocity in m/sec or miles/hour at nozzle N.
W	REAL	Initial vertical velocity in m/sec or miles/hour at nozzle N.
XS	REAL	Initial spatial variance of the material path in m^2 or ft^2 at nozzle N.
VS	REAL	Initial velocity variance of the material in m^2/sec^2 or ft^2/sec^2 at nozzle N.
		All initial conditions are set to zero unless modified by card 0062 for each nozzle. Card 0062 is ideal for an AGDISP run with few nozzles, such as a ground sprayer simulation.

0064 DIAM FRAC

Variable	Type	Description (Drop Size Card)
DIAM	REAL	Initial diameter of the drop in microns.
FRAC	REAL	Mass fraction assigned to this drop size. The sum of the mass fractions for all drop sizes in the simulation must equal 1.0 or less.

Up to 16 drop sizes may be specified in one AGDISP run. Drop sizes and their mass fractions may be estimated for common spray materials using DROPSIZE (Teske 1990b) and combining categories with SDC (Teske 1989d).

0065 DTEMP VFRAC

Variable	Type	Description (Evaporation Card)
DTEMP	REAL	Wet bulb temperature difference in deg C or deg F. The program WETBULB (described in Section 8) may be used to generate this input.
VFRAC	REAL	Volatile fraction of the released material (the fraction of material that will evaporate; if no material evaporates, then VFRAC = 0.0).

If the wet bulb temperature difference entered on this card is zero, AGDISP assumes that evaporation will be parameterized, and expects subsequent cards 0066. If VFRAC is negative, material is removed from the simulation when it evaporates down to the absolute value of VFRAC.

0066 DEA DEB DEC

Variable	Type	Description (Evaporation Parameterization Card)
DEA	REAL	Coefficient A in microns in the material diameter equation

$$\text{Diameter} = A + Bt + Ct^2 \qquad (50)$$

Variable	Type	Description
DEB	REAL	Coefficient B in microns/sec.
DEC	REAL	Coefficient C in microns/sec^2.

These coefficients are compatible with the evaporation model in FSCBG (Teske and Curbishley 1991), and produce consistent evaporation results between AGDISP and FSCBG. The coefficient A must be identical to each material diameter entered on cards 0064 and in the same order (the order is NOT checked by AGDISP). The number of 0066 cards must equal the number of drop sizes (0064 cards).

0070 Z

Variable	Type	Description (Apparent Surface Height Card)
Z	REAL	Apparent height above the surface (in meters or feet) at which the material will deposit. The default condition requires impact of material at the surface (with an apparent height equal to zero). For a nonzero entry, when material intersects the apparent height, it is removed from the computation, just as though it had impacted the surface. A subsequent ground deposition plot with AGPLOT will recover the deposition of the material at the apparent height entered on this card.

0075 GDK

Variable	Type	Description (Circulation Decay Card)
GDK	REAL	Factor (nondimensional) that forces a time reduction in the circulation strength of the vortices. Default value is zero (no decay). If this entry is negative, its absolute value is taken as the circulation decay constant multiplied by the ambient turbulence level (m/sec or ft/sec). Teske 1988b suggests that for small material sizes, an appropriate entry on card 0075 is -0.56 m/sec.

0080 XBOD DZ

Variable	Type	Description (Wide Body Setup Card)
XBOD	REAL	Position in meters or feet of the front of the fuselage from the trailing edge of the wing (or the shaft centerline of the helicopter), positive measured upstream (by convention, then, this number must be positive).
DZ	REAL	Vertical distance in meters or feet off-setting the nose centerline of the fuselage from the nominal height of the wing (or rotor plane) given on card 0020. The fuselage is assumed to be axisymmetric. If card 0080 is present, cards 0081 must also be present to define the fuselage body shape.

0081 X SS

Variable	Type	Description (Wide Body Effect Cards)
X	REAL	Position in meters or feet, measured positive from the nose of the fuselage to the tail, increasing toward the tail.

SS	REAL	Cross-sectional area of the fuselage in m^2 or ft^2, corresponding to the x position. The first 0081 card should contain 0.0 for x and 0.0 for the area. The last 0081 card should contain 0.0 for the area. After the final 0081 card is read, wide-body effects are initialized by a source-sink velocity profile near the fuselage and an axisymmetric turbulent wake decaying behind the fuselage.

0090 N2FRO

Variable	Type	Description (To And Fro Card)
N2FRO	INT	AGDISP always computes results for the "to" direction, with the aircraft flying away from the observer; any nonzero entry on this card will also invoke a corresponding "fro" direction, with the aircraft flying toward the observer.

5. AGPLOT Inputs

The AGPLOT program may be invoked to plot the resulting trajectories and deposition pattern from an AGDISP run. The program asks questions interactively of the user, and with this information processes the data and plots the results.

At the beginning of AGPLOT, the log file is read, the input data deck used to generate the file is written to the screen (to serve as verification of the proper run to plot), and the log file is scanned for maximum values and available options. With this information in hand, AGPLOT then displays its current menu driver:

0	EXIT AGPLOT
1	Mean drop trajectories
2	Mean + standard deviation trajectories
3	Vortices/helicopter/engine centroids
4	Continuous ground deposition
5	Volume median diameter
6	Number median diameter
7	Layered canopy deposition
8	Total canopy deposition
9	Vertical flux profile
10	Equivalent gaussian distribution
11	Crosswind velocity profile
12	Canopy plant area fraction profile
13	Drop diameter time history
14	Drop canopy parameter time history
15	Drop velocity time history
16	Object deposition time history
17	Drift fraction time history
18	Coefficient of variation profile
19	Swath deposition overlap pattern

followed by the request "Enter option to run". Only those options available from the saved datafiles will be displayed. Each of the options is described as follows:

0 is entered to exit from AGPLOT. Since several menu options may be invoked for one AGDISP run, 0 is the entry used to complete the plotting for a particular log file.

1 is entered to plot the mean trajectories. If more than one drop size was solved (with more than one card 0064), AGPLOT will display the available BIN file numbers ("LOG file contains more than one BIN file"), and their corresponding initial drop diameters, and asks

Enter BIN file to access

to select the datafile to read.

2 is entered to plot the mean trajectories (as solid curves) and the standard deviation of the mean trajectories (as dashed curves).

3 is entered to plot the trajectories of the vortex centroids (as solid curves) and the center(s) of the propeller, jet engine or helicopter (as dashed curves), if applicable. This option is available only with an appropriate nonzero entry on card 0011 in AGDISP.

4 is entered to compute and plot the composite ground deposition pattern with continuous deposition following Eq. (46). Up to 16 drop sizes may be combined in this plot, as specified by cards 0064 in the input deck. If "to" and "fro" calculations have been invoked with card 0090, the user is asked

LOG file contains To and Fro calculations ...
Which direction to access (T/F)

with the "to" direction (T) as default. Seven scales are available in AGPLOT:

1 normalized
2 liters/hectare
3 fluid ounces/acre
4 gallons/acre
5 mg/sq m
6 nl/sq cm
7 drops/sq cm

Also, if the volatile fraction is nonzero (meaning there is evaporation), AGPLOT asks

Plot nonvolatile contribution only (N/Y)

with no (N) as the default. If the nonvolatile contribution is invoked, "NONVOLATILE" appears in the upper right corner of the plot. For the normalized deposition plot, an integral under the deposition curve reflects the amount of material that has impacted the surface. This number appears in the lower left corner of the plot.

When the calculation is completed, AGPLOT asks

Save ASCII data (N/Y)

to permit the user to port the results into an alternate graphics package. If the response is yes (Y), AGPLOT asks

Enter FILENAME.EXT

for the user to enter an appropriate filename designation to save the results. Results are saved in a two-column format file, where the first column is the horizontal position relative to the aircraft centerline (the y distance), in meters measured from left to right; and the second column is the corresponding values in the scale previously selected.

5 is entered to compute and plot the total volume median diameter of all material deposited on the ground. The average VMD over the deposition appears in the lower left corner of the plot.

6 is entered to compute and plot the total number median diameter of all material deposited on the ground. The average NMD over the deposition appears in the lower left corner of the plot.

7 is entered to compute and plot contours of the composite canopy deposition pattern following incremental Gaussian deposition (Eq. 44) through the canopy. Deposition is computed in layers through the canopy. The user is then quizzed to give specific contour values to be plotted, or to permit AGPLOT to autoscale the contour values. Option 7 must be exercised to generate the profile distribution needed for option 8. The maximum deposition value appear in the lower left corner of the plot.

8 is entered to plot the total canopy deposition determined in option 7.

9 is entered to compute and plot the total flux through a vertical plane defined by the user in response to the question

Enter Y position of plane (m)

Total vertical flux is the sum over time of the material passing through the specified plane. The y position is shown in the upper left corner of the plot.

10 is entered to compute and display the equivalent Gaussian distribution. Since the position and standard deviation of all material in the simulation is computed by AGDISP as a function of time after release, the equivalent mean position and standard deviation may be determined by appropriate summation and integration at each time over all material in the simulation. A measure of the compatibility of the equivalent Gaussian distribution is made by computing a figure of merit ranging from 0 to 1. When the equivalent Gaussian no where represents the multiple-drop distribution, the figure of merit equals zero. When the equivalent Gaussian is everywhere identical to the multiple distribution, the figure of merit is unity. Equivalent Gaussian calculations are made for every time in the designated plot file, with all times given a sequence number. The critical sequence number, the time associated with each of them, and their respective figure of merit and terminal velocity criterion are displayed on the screen whenever: the first sequence number is reached; the last sequence number is reached; the figure of merit reaches a local minimum; the figure of merit reaches a local maximum; or material first comes within a standard deviation of the ground.

The terminal velocity for the material size examined is computed assuming no evaporative effects and a specific gravity of unity. It is displayed with the message "Terminal velocity" as reference to the user. The terminal velocity criterion is computed as the average over all material of their vertical velocities relative to their terminal velocity (if all material were moving at

their terminal velocity, the WCRIT value would be 1.0). Option 10 requires that vertical velocities be saved on the plot file by the appropriate input on card 0011 in AGDISP. Material whose vertical velocities are not within fifty percent of their terminal velocity will not contribute to the figure of merit calculations at that time step.

After processing the entire plot file and displaying the above summary information, the plot file is reread to locate the position of maximum figure of merit. At this point the equivalent Gaussian data is displayed on the screen. If the equivalent Gaussian vertical standard deviation contacts the surface, the warning message "Ground encounter by equivalent gaussian" will be displayed on the screen.

The resulting plot represents each released material distribution as dashed curves and the single equivalent Gaussian distribution as solid curves. Around each center point of the material contributing to the equivalent Gaussian, normalized contour lines are plotted at one-fourth and one times the standard deviation. Material not contributing to the equivalent Gaussian are plotted with much smaller ellipses to aid in identifying them. The figure of merit appears in the lower left corner of the plot.

11 is entered to plot the crosswind velocity profile (if available with a 0028 card or 0029 cards in AGDISP).

12 is entered to plot the canopy plant area fraction profile (if available with 0055 cards in AGDISP).

13 is entered to plot the time history of a drop diameter (if evaporation is occurring). If there are more than one nozzle in the simulation, AGPLOT requests

Enter nozzle to process

The selected nozzle number is displayed in the lower left corner of the plot.

14 is entered to plot the time history of the canopy deposition of a drop (if canopy cards 0055 are present in AGDISP).

15 is entered to plot the velocity time history of a drop (if the mean velocity data is stored on the plot file with card 0011 in AGDISP). AGPLOT asks

1 U axial velocity
2 V horizontal velocity
3 W vertical velocity

to enable the user to select one of the velocities for the plot. The selected velocity (U AXIAL, V HORIZONTAL or W VERTICAL) is written to the lower right corner of the plot.

16 is entered to compute and plot the time history of the deposition on a specified collector geometry at a specified position in the AGDISP solution field (mean velocity data must be stored on the plot file with card 0011 in AGDISP). The collector must first be placed in the solution field by responding to the request

Enter (Y,Z) collector location (m)

with the y and z values entered in meters. Next, AGPLOT asks for the type of collector; currently, the options are:

1 Card
2 Cylinder
3 Sphere

Then AGPLOT requests

Enter significant target dimension (m)

to give a typical length of the collector in meters. Finally, AGPLOT needs to know the orientation of the collector relative to the (x,y,z) coordinate system, and asks

Enter (X,Y,Z) normal vector

Here all three components must be entered; AGDISP renormalizes into a unit vector. A preferred normal direction must be supplied, even for collectors that do not appear to have planar geometry. If the collector were placed parallel to the surface, the normal vector would be (0,0,1). If the collector were vertical and deposition on the left side were needed, the normal vector would be (0,-1,0).

The total amount of material collected on the collector appears in the lower left corner of the plot. The collection efficiency appears in the lower right corner of the plot.

17 is entered to compute and plot the time history of the drift of all of the drops in the simulation. The final drift fraction appears in the lower left corner of the completed plot.

18 is entered to compute and plot the coefficient of variation as a function of lane separation between flight lines of the aircraft. Option 4 (continuous ground deposition) must be invoked to generate the ground deposition before option 18 can be invoked to overlap the deposition to compute lane separation effects. Number depositions (in drops/sq cm) should not be used for lane separation computations. If both "to" and "fro" ground depositions are available, the user will be asked to select one of the options

Which direction to access (T/F/C)

where the default is "to" (T), a response of F will invoke "fro" and a response of C will invoke a combined deposition, alternating between the

two saved depositions to compute a composite pattern. The complete plot will include, in the lower left corner, the value of lane separation at a coefficient of variation of 0.3, or at the curve minimum location. This value of COV is suggested in the literature (Teske, Twardus and Ekblad 1990). If the resultant curve for COV is not "smooth" enough, a smaller horizontal distance must be chosen in option 4 for continuous ground deposition.

19 is entered to compute and plot the effective swath pattern if multiple flight lines are overlapped at a lane separation specified by the user

Enter lane separation distance (m)

The lane separation (from option 18), or any other separation value, may be entered here. Option 4 (continuous ground deposition) must be invoked to generate the ground deposition before option 19 can be invoked to overlap the deposition. If both "to" and "fro" ground depositions are available, the user will be asked to select one of the options

Which direction to access (T/F/C)

The complete plot will include, in the lower left corner, the average deposition value over the swath width (in the user specified deposition units).

Where appropriate, the following requests are made by AGPLOT:

Autoscale canopy contours (Y/N)

AGPLOT contour plots appropriate deposition levels through the canopy in option 7. If N is the response, AGPLOT gives the maximum deposition value and asks for contour levels (and will plot them) until a negative deposition value is entered.

Autoscale computation grid (Y/N)

AGPLOT computes appropriate solution intervals, if invoked, for options that require a specified grid before computations can occur. If N is the response, AGPLOT asks

Enter Y scale min, max

or

Enter Z scale min, max (in option 9 only)

Autoscale plot axes (Y/N)

AGPLOT computes appropriate plotting scales if invoked. If N is the response, AGPLOT asks

Enter Y scale min, max, incr

and

Enter Z scale min, max, incr

AGPLOT has a scale checking routine and invokes a warning message whenever the scale delta is not an integer fraction of the overall scale size. Additionally, three errors will be trapped: "Maximum scale less than minimum scale"; "Scale increment less than zero"; and "Too many scale divisions" whenever more than ten scale divisions are needed.

Available scales
1 normalized
2 liters/hectare
3 fluid ounces/acre
4 gallons/acre
5 mg/sq m
6 nl/sq cm
7 drops/sq cm
Enter scale to use

One of the available units must be selected by the user. The "normalized" scale produces a nondimensional result.

Collector types
1 Card
2 Cylinder
3 Sphere
Enter type to use

Option 16 requires the selection of a collector type.

Enter FILENAME.EXT

At this prompt the user enters the name of the ASCII datafile into which the results are stored.

Enter lane separation distance (m)

Option 19 requests the distance between flight lines to construct the overlapped swath deposition pattern.

Enter nozzle to process

Several options require the selection of one of the nozzles in the simulation.

Enter plot title

The user enters the desired title for the current plot (a maximum of 32 characters).

Enter significant target dimension (m)

Option 16 requires the size of the collector in meters.

Enter (X,Y,Z) normal vector

Option 16 requires the orientation of the collector relative to the coordinate system of the AGDISP solution.

Enter Y position of plane (m)

Option 9 requires a y position in the AGDISP solution through which to evaluate vertical flux.

Enter (Y,Z) collector location (m)

Option 16 requires the placement of a collector (in meters) in the AGDISP solution.

LOG file contains more than one BIN file ...
Enter BIN file to access

Several options require the selection of one drop size. When more than one are solved by AGDISP, the user is asked to select the one to access.

LOG file contains To and Fro calculations ...
Which direction to access (T/F)

Several options require the selection of aircraft direction (if the "fro" or F option is available with card 0090 in AGDISP).

Plot nonvolatile contribution only (N/Y)

When evaporation is active (with card 0065 in AGDISP), AGPLOT permits the user to plot the nonvolatile (nonevaporative) part of the material alone (with a response of Y), or to plot the total material.

Save ASCII data (N/Y)

Several options permit the results to be written to a readable file for porting to other graphics applications.

Tag location at time increments (N/Y)

This option is asked for mean trajectories, to tag released material positions on the plot as a function of time. The size of the tag is scaled to the size of the material standard deviation. If the response is Y, AGPLOT asks

Enter tag time increment

to enter the incremental seconds between tags.

To and Fro directions have been saved ...
Which direction to access (T/F)

If the "fro" direction is active (with card 0090 in AGDISP) and both the "to" and "fro" canopy depositions (option 7) have been invoked, the user may select "to" or "fro" for option 8.

To and Fro directions have been saved ...
Which direction to access (T/F/C)

If the "fro" direction is active (with card 0090 in AGDISP) and both the "to" and "fro" ground depositions (option 4) have been invoked, the user may select "to" or "fro", or an alternating deposition pattern "combined" for option 18 (if both "to" and "fro" have been saved with the same deposition units and either total or nonvolatile contributions).

Velocities

1 U axial velocity
2 V horizontal velocity
3 W vertical velocity

Enter velocity to plot

In option 15 one of the three velocities (U,V,W) must be specified.

On the Data General the following additional messages are possible:

Enter MASTER filename

The filename containing the data to be read (12 characters or less without extension) is entered here.

Enter METAFILE.EXT for this plot

If metafiles are open (from a previous query), then each plot must be assigned a name and extension for storing on the DG system in the user directory. A metafile extension of GKM is recommended for entry into CEO.

Enter printer device type

Response to this query determines the hardcopy device used. A nonblank entry will invoke the QUE name request. A blank entry will prevent any output from being hardcopied.

Enter QUE name code

A hardcopy unit must be specified by its queue name within the DG environment. If a blank name is given, hardcopy of plots will not occur.

Enter workstation type

Response to this query determines the terminal screen used.

Open output METAFILES (N/Y)

Plots may be spooled to a file for later manipulation. This option permits that operation.

Plot completed: press RETURN to continue

The DG system blanks the screen after completing a plot unless a pause is programmed into AGPLOT.

Additionally, on the DG system the pressing of any function key at a query line returns the user to the menu driver.

6. Test Cases

Four test cases are included in the User Manual to illustrate the variety of data entry available with AGDISP. These examples are included to demonstrate the structure of the input data and the data entry requirements of each type of data card and option. They are not meant to suggest that certain options go with certain other options, nor are all options covered.

The four examples illustrate the following features:

1. The first test case examines the wake behind an F-15 fighter flying at Mach 0.5. Because of the high speed, Betz roll-up is invoked, with a wing load distribution obtained from vortex-lattice theory. Figure 6-1 displays the appropriate input deck. Figure 6-2 shows the mean trajectories and Figure 6-3 shows the ground deposition in drops per square centimeter.

2. The second test case examines the wake behind a wide body C-130 transport plane. Figure 6-4 displays the appropriate input deck. Figure 6-5 shows the mean trajectories; Figure 6-6 includes the spread of released material due to turbulence; Figure 6-7 shows the paths of the tip vortices and propellers; and Figure 6-8 shows the ground deposition in ounces per acre.

3. The third test case examines the wake behind a Cessna 188 Ag Truck in forward flight (Mission test run 14, droplet size 171 microns, Teske 1988). Figure 6-9 displays the input deck while Figure 6-10 shows the mean trajectories and Figures 6-11 and 6-12 show the ground deposition for all of the material (in liters per hectare), and for the nonvolatile part (normalized). Figures 6-13 and 6-14 show the VMD and NMD plots, while Figure 6-15 gives a vertical flux plot (in liters per hectare) at a y plane position of -10 meters in the AGDISP coordinate system. Figure 6-16 illustrates the equivalent Gaussian distribution; Figure 6-17 shows the crosswind velocity profile; Figure 6-18 shows the time history of the evaporating diameter from one nozzle in the simulation; Figures 6-19, 6-20 and 6-21 give the corresponding drop velocity time histories; and Figure 6-22 shows the deposition on a spherical collector. Figures 6-23 and 6-24 illustrate the drift fraction for all of the material, and for the nonvolatile part. Finally, Figures 6-25 and 6-26 show the coefficient of variation for this example case, and the resulting overlapped swath pattern.

4. The fourth test case examines a Hiller 12E helicopter (Chico test run B-2, Teske 1989c). Figure 6-27 displays the input file, while Figure 6-28 shows the mean trajectories and Figure 6-29 shows the ground deposition in gallons per acre. Figure 6-30 displays contours of canopy deposition, while Figure 6-31 summarizes the total deposition through the canopy, on the same scale as the ground deposition. Figure 6-32 illustrates the crosswind velocity profile; Figure 6-33 illustrates the canopy plant area fraction profile; Figure 6-34 gives the canopy deposition fraction from one nozzle in the simulation; and Figure 6-35 summarizes the drift fraction for the simulation.

```
0000  F-15
0010  50.0
0011  100  0  0  0
0020  0  6.67  20.0  170.0
0025  0.0     139.288
0025  0.102  139.288
0025  0.297  139.158
0025  0.482  138.911
0025  0.668  138.540
0025  0.853  138.045
0025  1.038  137.424
0025  1.223  136.678
0025  1.409  135.805
0025  1.594  134.805
0025  1.779  133.677
0025  1.965  132.418
0025  2.150  131.028
0025  2.335  129.505
0025  2.520  127.845
0025  2.706  126.046
0025  2.891  124.104
0025  3.076  122.017
0025  3.262  119.779
0025  3.447  117.385
0025  3.632  114.828
0025  3.817  112.097
0025  4.016  109.087
0025  4.215  105.890
0025  4.400  102.636
0025  4.586   99.170
0025  4.771   95.449
0025  4.956   91.428
0025  5.142   87.053
0025  5.327   82.248
0025  5.512   76.906
0025  5.697   70.873
0025  5.859   64.330
0025  6.022   56.753
0025  6.207   47.080
0025  6.392   35.380
0025  6.577   20.145
0025  6.670    0.0
0035  95400.0  0.5  -0.6  -3.0
0045  2  0.6  -0.6
0050  0  1.0
0060  4  0.0  0.5  1.0  4.0
0061  -4.4467  -1.0
0061  -2.2233  -1.0
0061   2.2233  -1.0
0061   4.4467  -1.0
0064  300.0  1.0
```

Figure 6-1 AGDISP input file for Example Case 1.

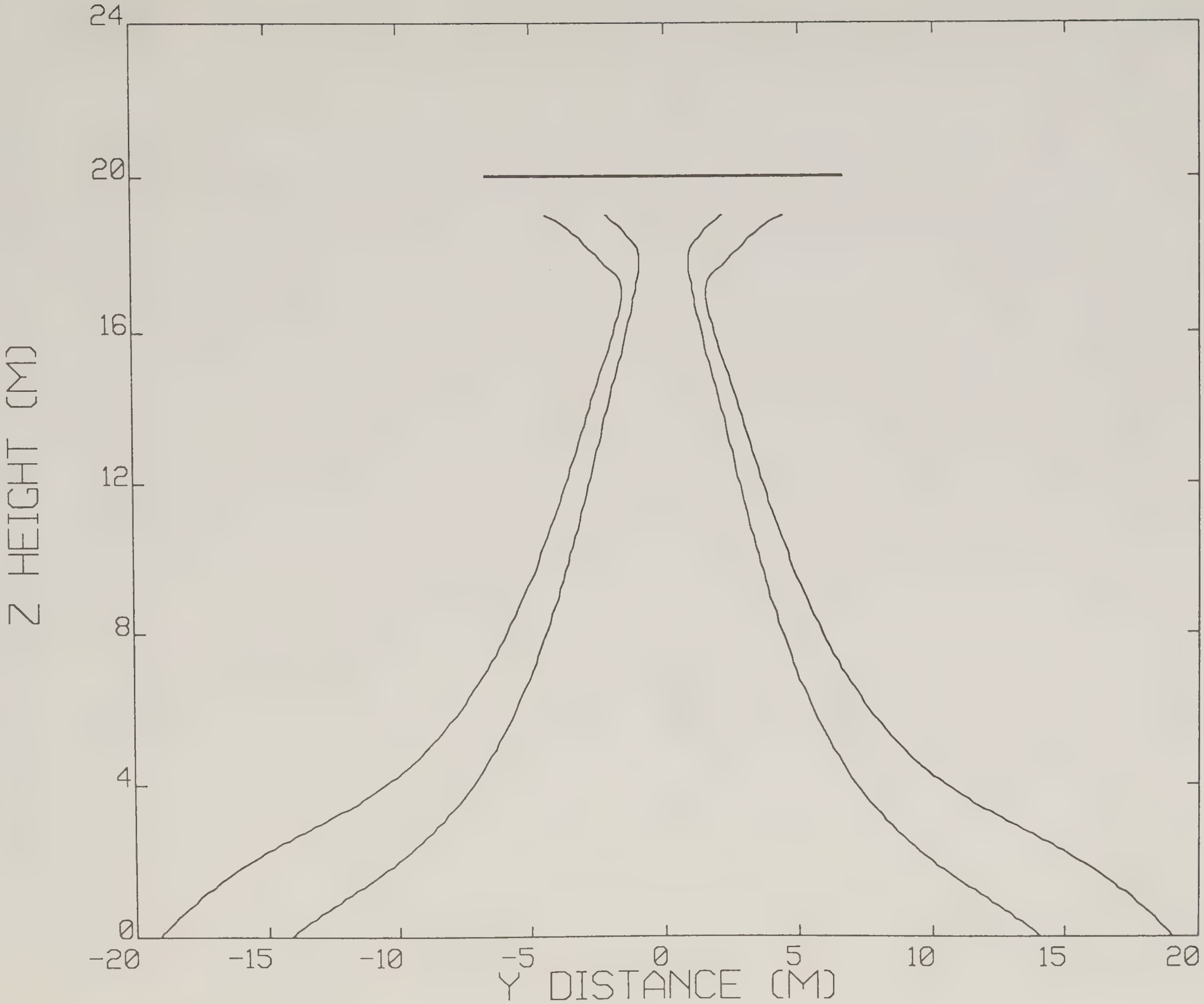

Figure 6-2 Mean trajectories for Example Case 1. The wing position is indicated by the double-wide solid line.

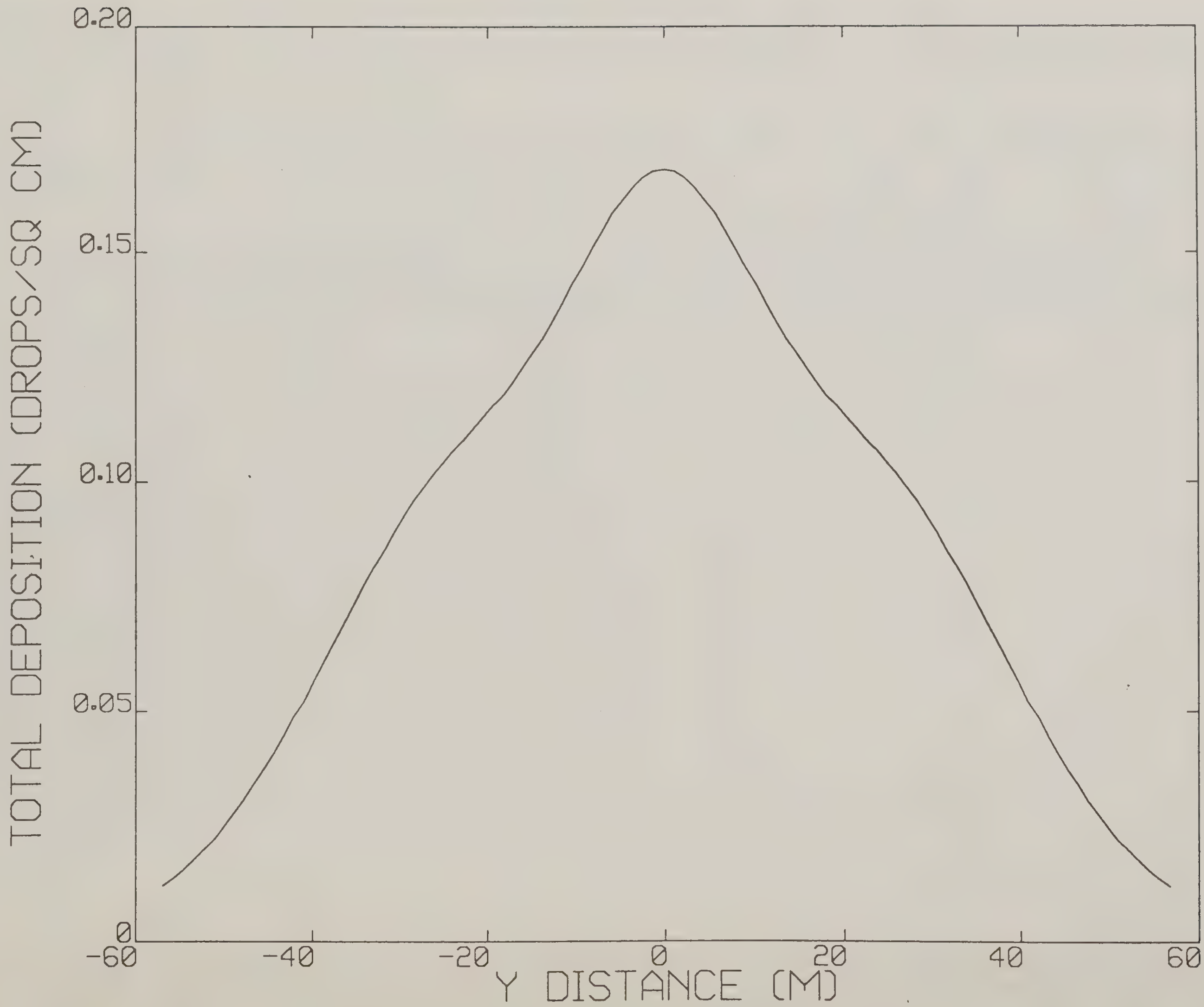

Figure 6-3 Continuous ground deposition for Example Case 1.

```
0000  C-130
0010  30.0
0011  100  100  0  0
0020  2  20.2  20.0  150.0
0023  625000.0
0040  0.1  40.0  0.8  2500.0  2.05  -0.9  5.0
0045  4  5.1  -0.9  10.1  -0.9
0050  0  1.0
0060  4  0.0  0.0  1.0  4.0
0061  -12.5  -3.8
0061   -5.0  -3.8
0061    5.0  -3.8
0061   12.5  -3.8
0064  200.0  1.0
0080  14.0  -2.6
0081   0.0   0.0
0081   4.5   7.21
0081   8.8   7.58
0081  13.3   9.53
0081  16.7   7.91
0081  18.0   6.76
0081  20.0   5.88
0081  22.2   3.06
0081  24.0   2.05
0081  29.2   0.0
```

Figure 6-4 AGDISP input file for Example Case 2.

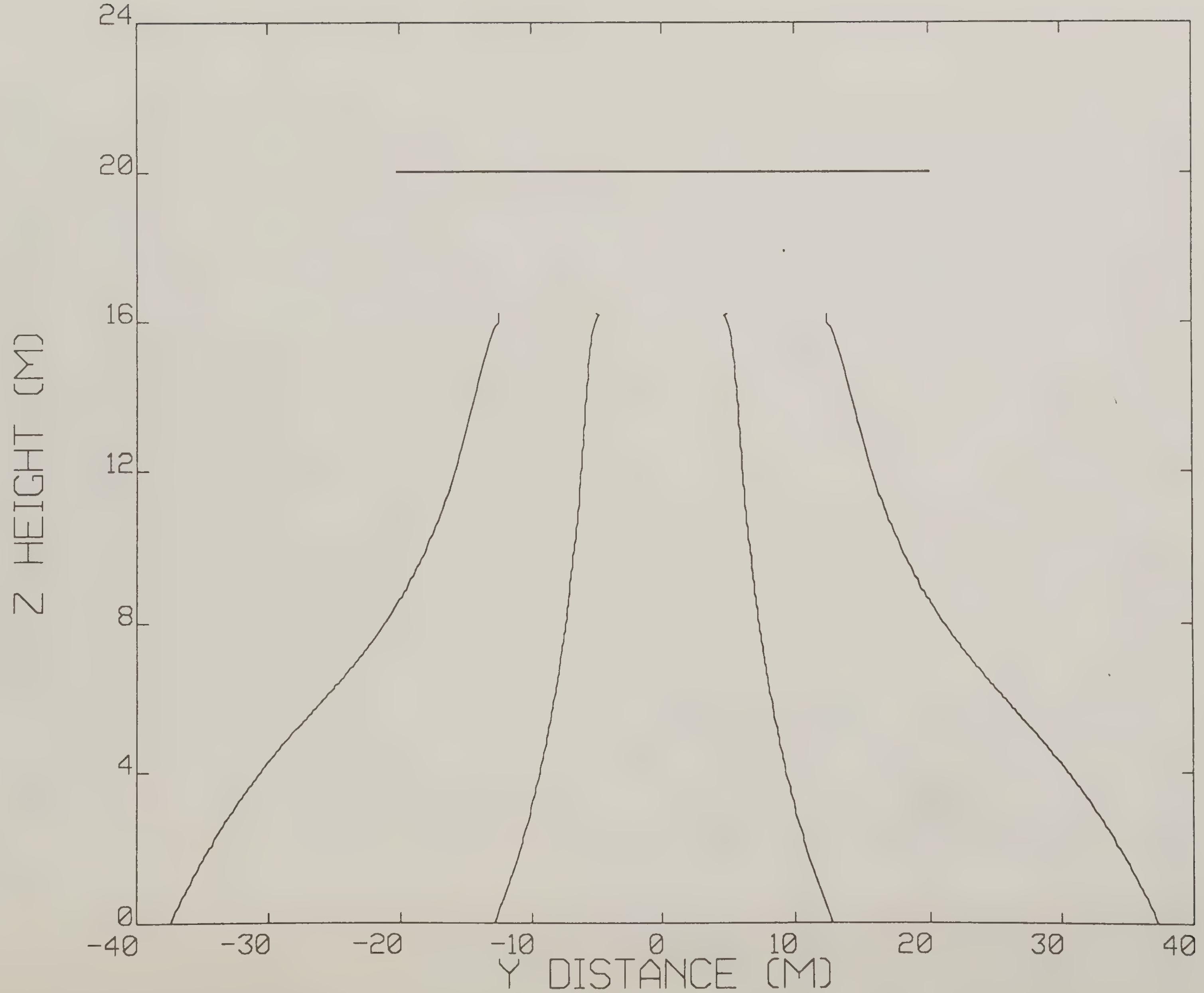

Figure 6-5 Mean trajectories for Example Case 2.

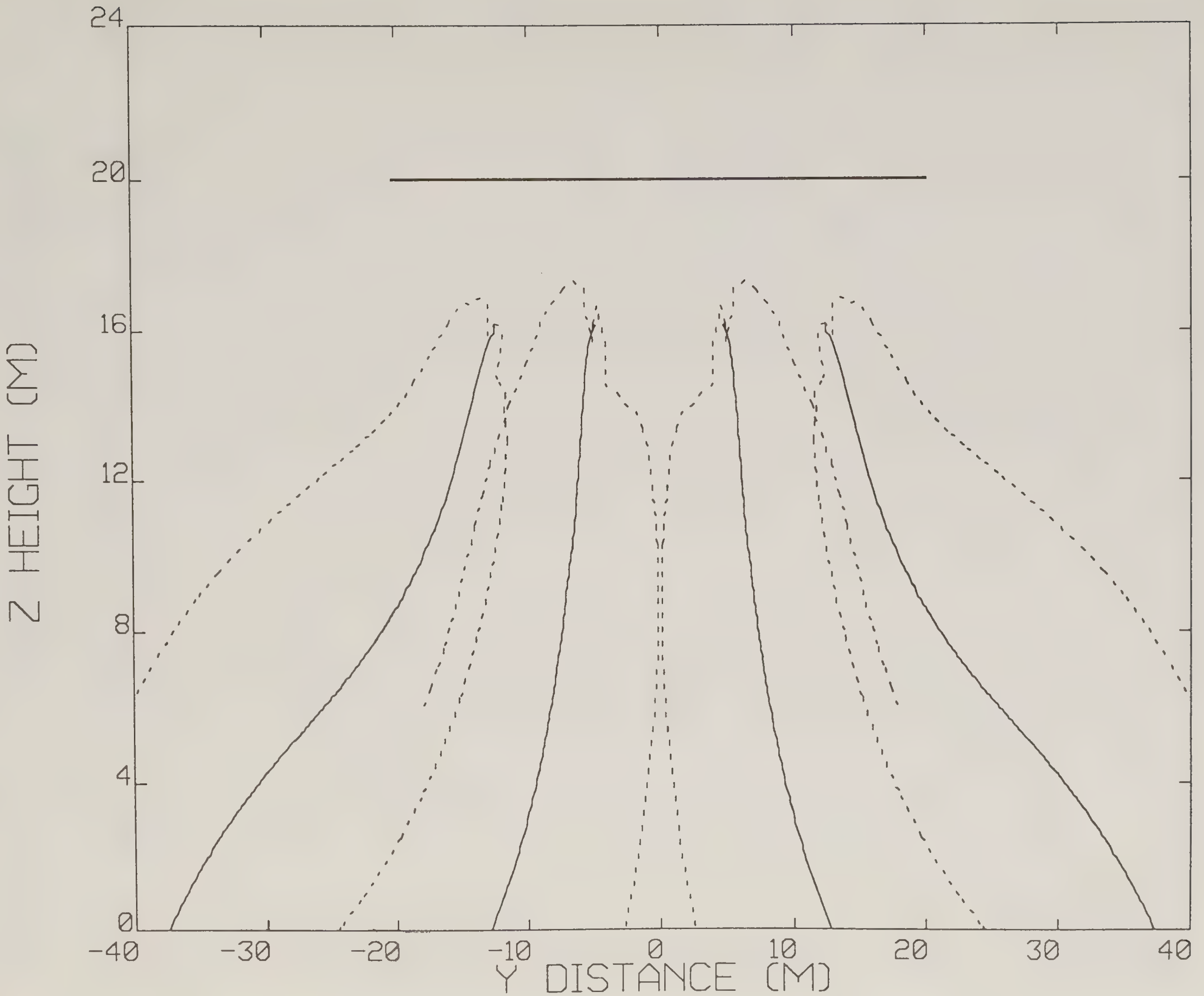

Figure 6-6 Mean trajectories (solid) and standard deviations around the mean trajectories (dashed) for Example Case 2.

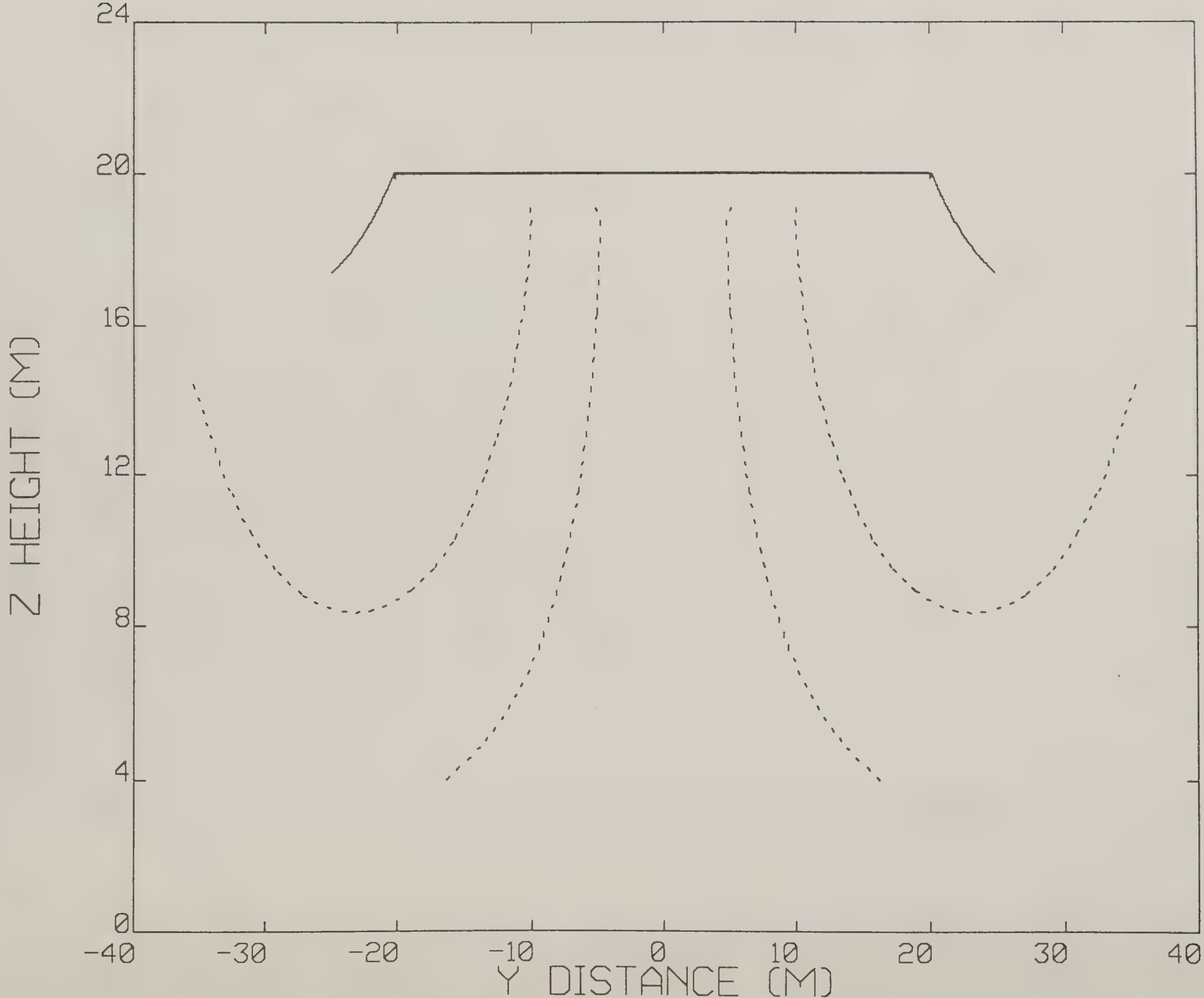

Figure 6-7 Paths of the tip vortices (solid) and engine centerlines (dashed) for Example Case 2.

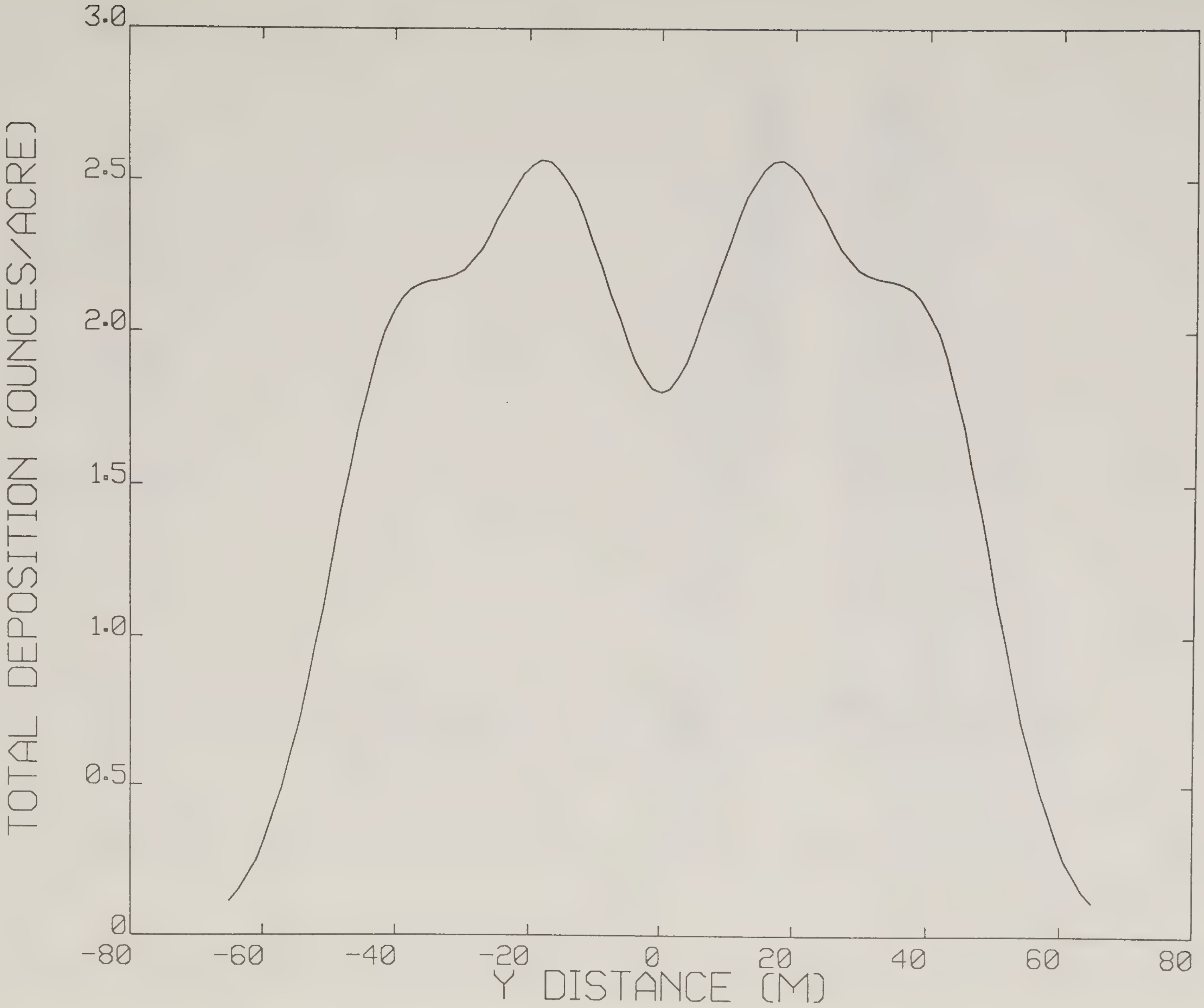

Figure 6-8 Continuous ground deposition for Example Case 2.

```
0000  CESSNA 188 AG TRUCK
0010  180.0
0011  100  0  0  1
0020  2  6.37  15.55  49.6
0023  14362.5
0028  6.11  10.0  0.0134  1.25
0040  0.1  19.05  0.8  2400.0  1.02  -0.4  0.0
0050  0  0.0
0060  47  0.0  0.0  1.0  4.7
0061  -5.093  -0.244
0061  -4.940  -0.257
0061  -4.788  -0.295
0061  -4.623  -0.339
0061  -4.470  -0.396
0061  -4.318  -0.422
0061  -4.166  -0.447
0061  -4.007  -0.485
0061  -3.848  -0.523
0061  -3.696  -0.549
0061  -3.543  -0.600
0061  -3.378  -0.625
0061  -3.188  -0.650
0061  -3.035  -0.676
0061  -2.883  -0.695
0061  -2.724  -0.708
0061  -2.572  -0.739
0061  -2.413  -0.752
0061  -2.261  -0.777
0061  -2.108  -0.790
0061  -1.956  -0.822
0061  -1.638  -0.847
0061  -1.334  -0.892
0061   1.334  -0.892
0061   1.499  -0.873
0061   1.651  -0.854
0061   1.803  -0.828
0061   1.962  -0.815
0061   2.273  -0.777
0061   2.426  -0.752
0061   2.584  -0.746
0061   2.743  -0.714
0061   2.896  -0.695
0061   3.048  -0.676
0061   3.200  -0.650
0061   3.397  -0.625
0061   3.556  -0.600
0061   3.708  -0.568
0061   3.861  -0.542
0061   4.013  -0.511
0061   4.166  -0.485
0061   4.318  -0.447
0061   4.477  -0.434
0061   4.636  -0.396
0061   4.788  -0.365
0061   4.934  -0.333
0061   5.105  -0.295
0064  171.0  1.0
0065  3.65  0.536
```

Figure 6-9 AGDISP input file for Example Case 3.

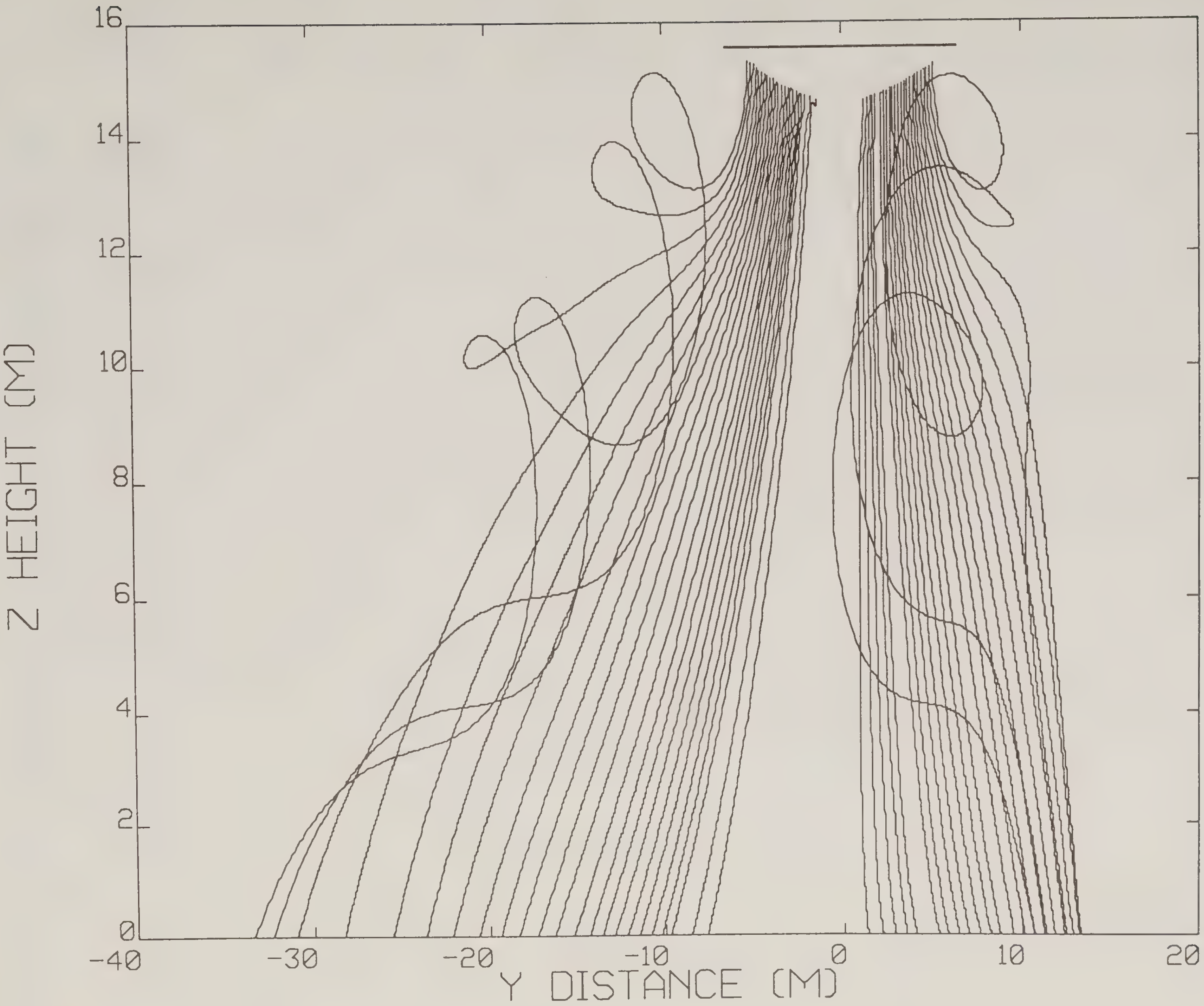

Figure 6-10 Mean trajectories for Example Case 3.

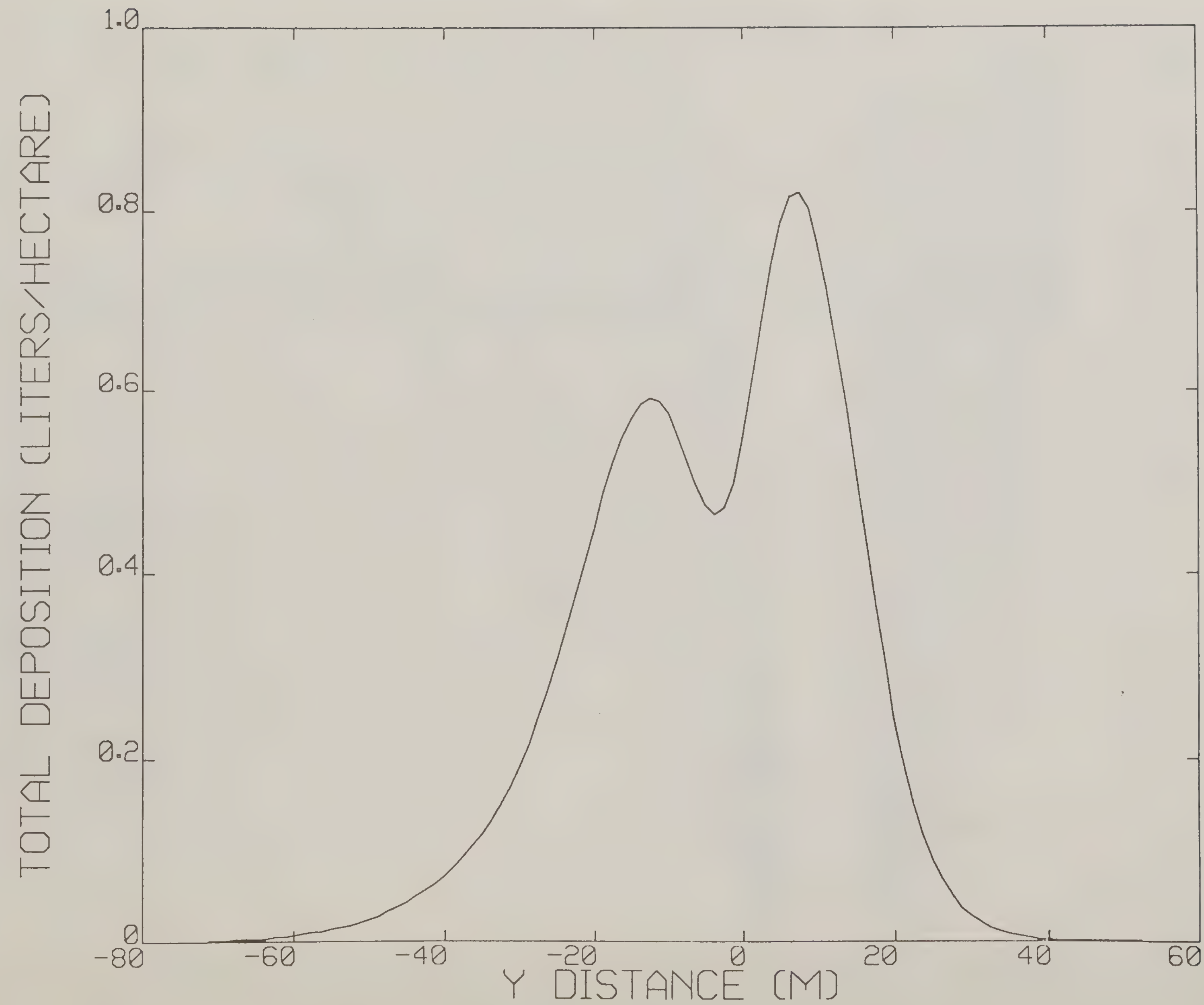

Figure 6-11 Continuous ground deposition for Example Case 3.

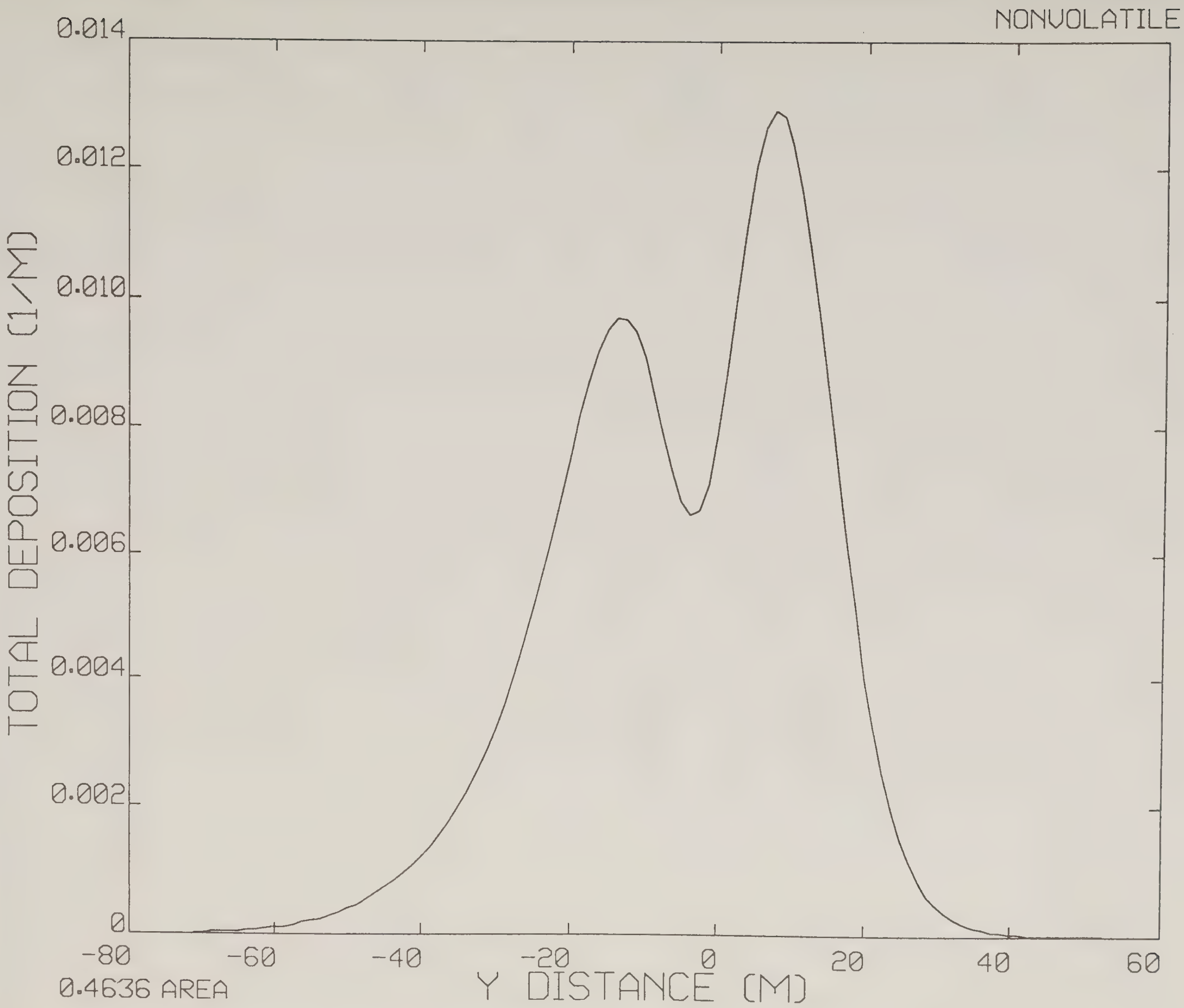

Figure 6-12 Continuous ground deposition (nonvolatile) for Example Case 3. With the "normalized" scale selected, the area under the curve is also displayed. Card 0065 in Figure 6-9 shows a volatile fraction of 0.536, which means that ideally 0.464 of the released material will be nonvolatile.

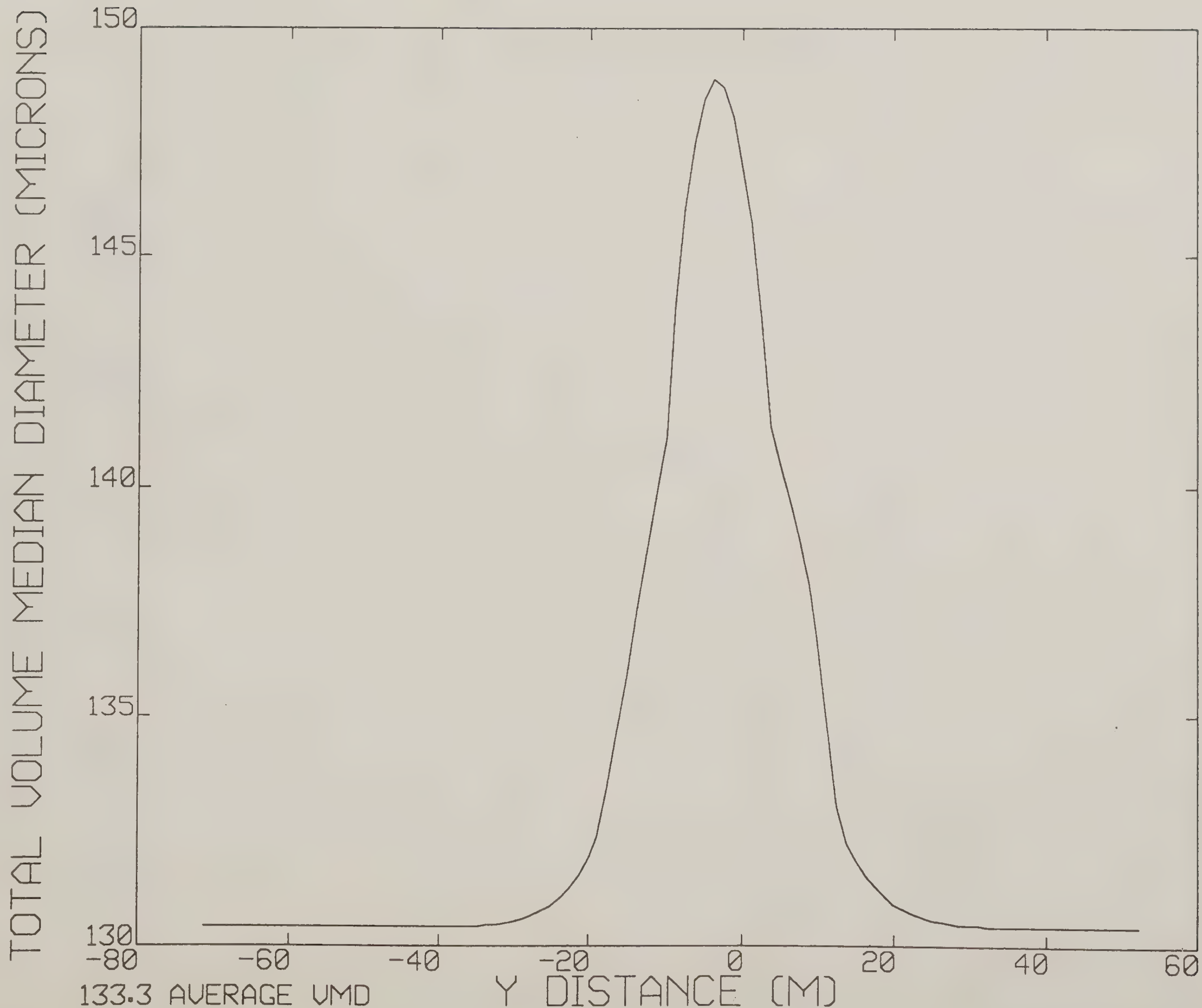

Figure 6-13 Volume median diameter at the ground for Example Case 3. The average drop size of 133.3 microns is also displayed.

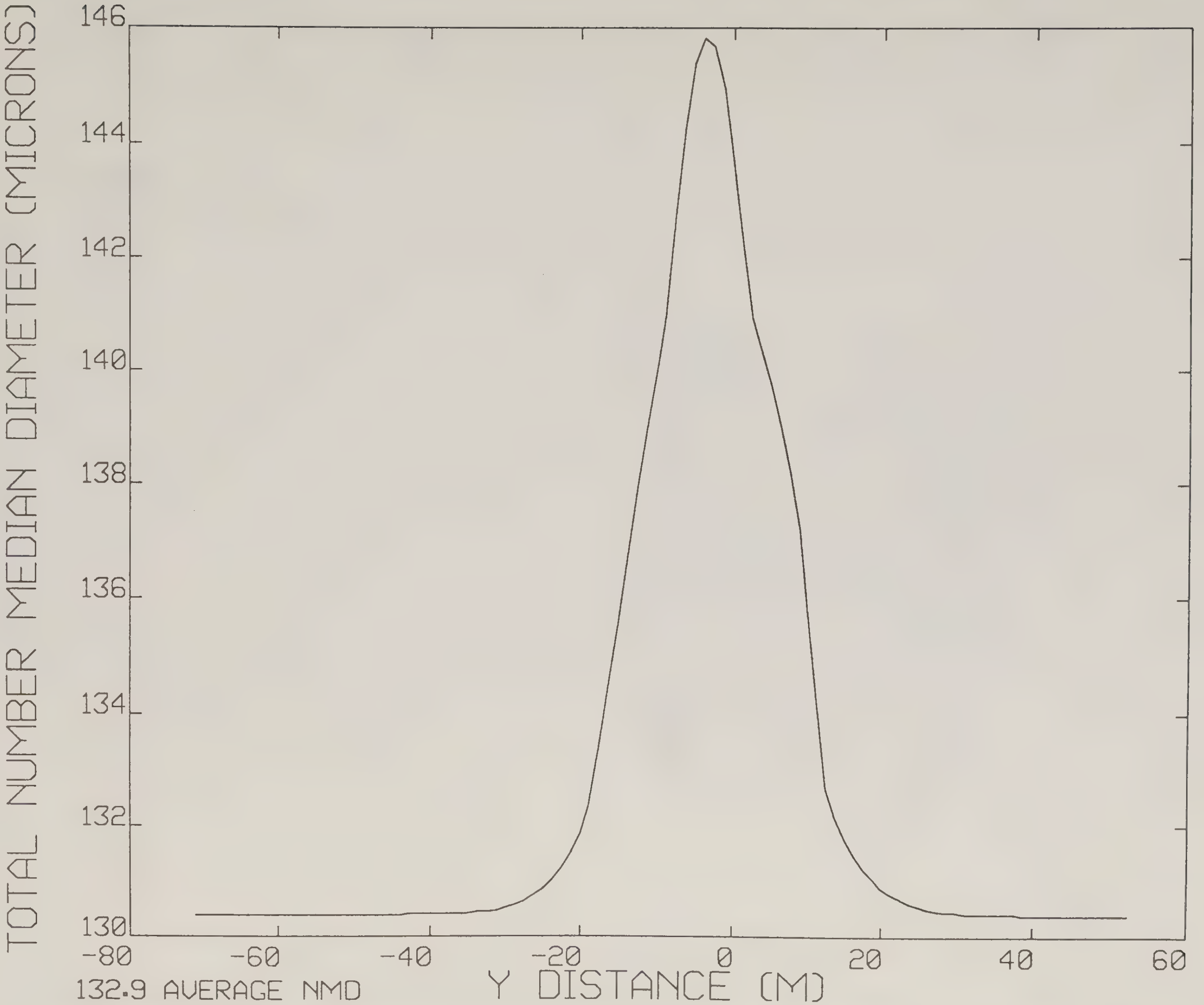

Figure 6-14 Number median diameter at the ground for Example Case 3. The average drop size of 132.9 microns is also displayed.

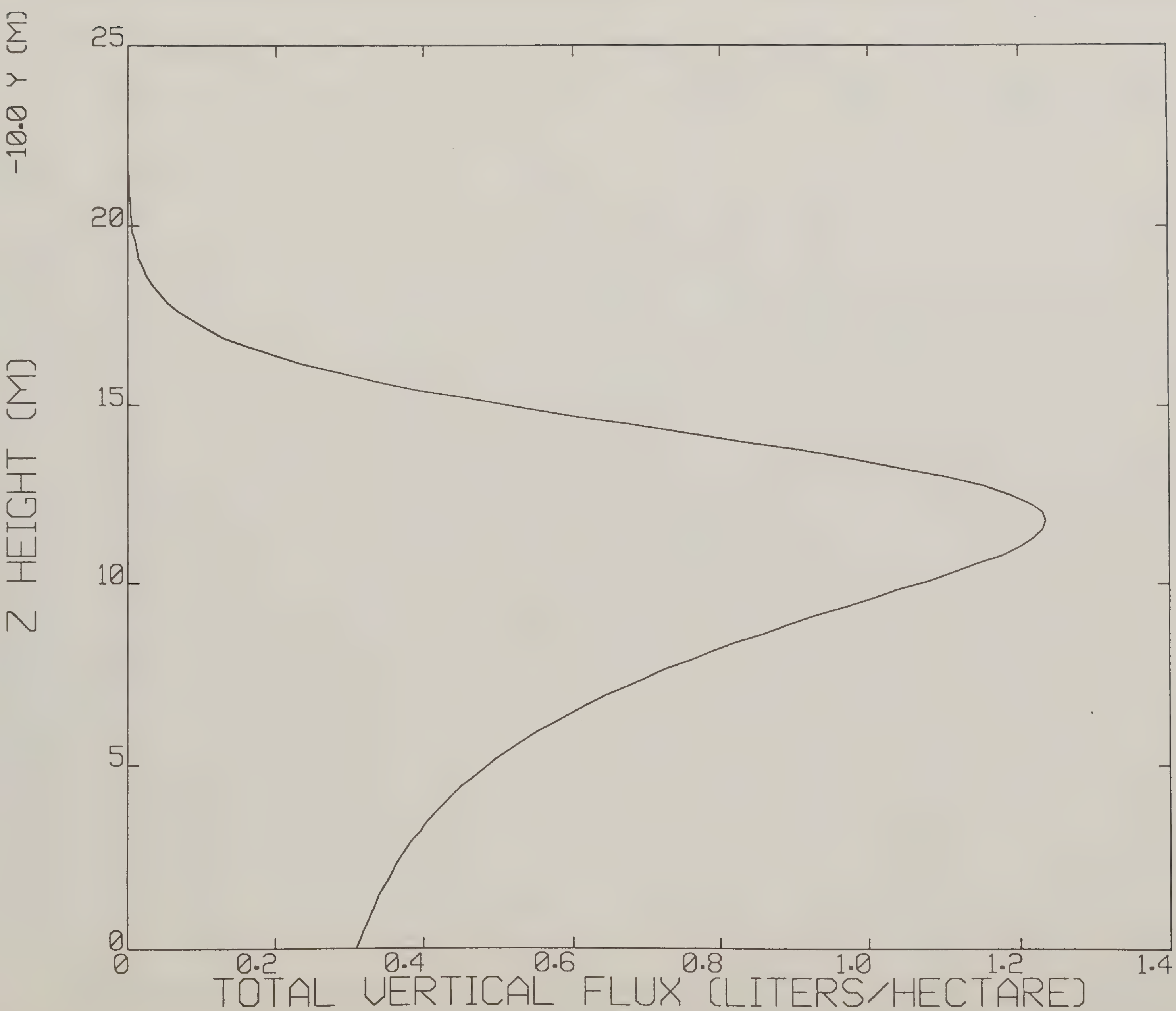

Figure 6-15 Vertical flux through a plane located at y = -10 meters for Example Case 3.

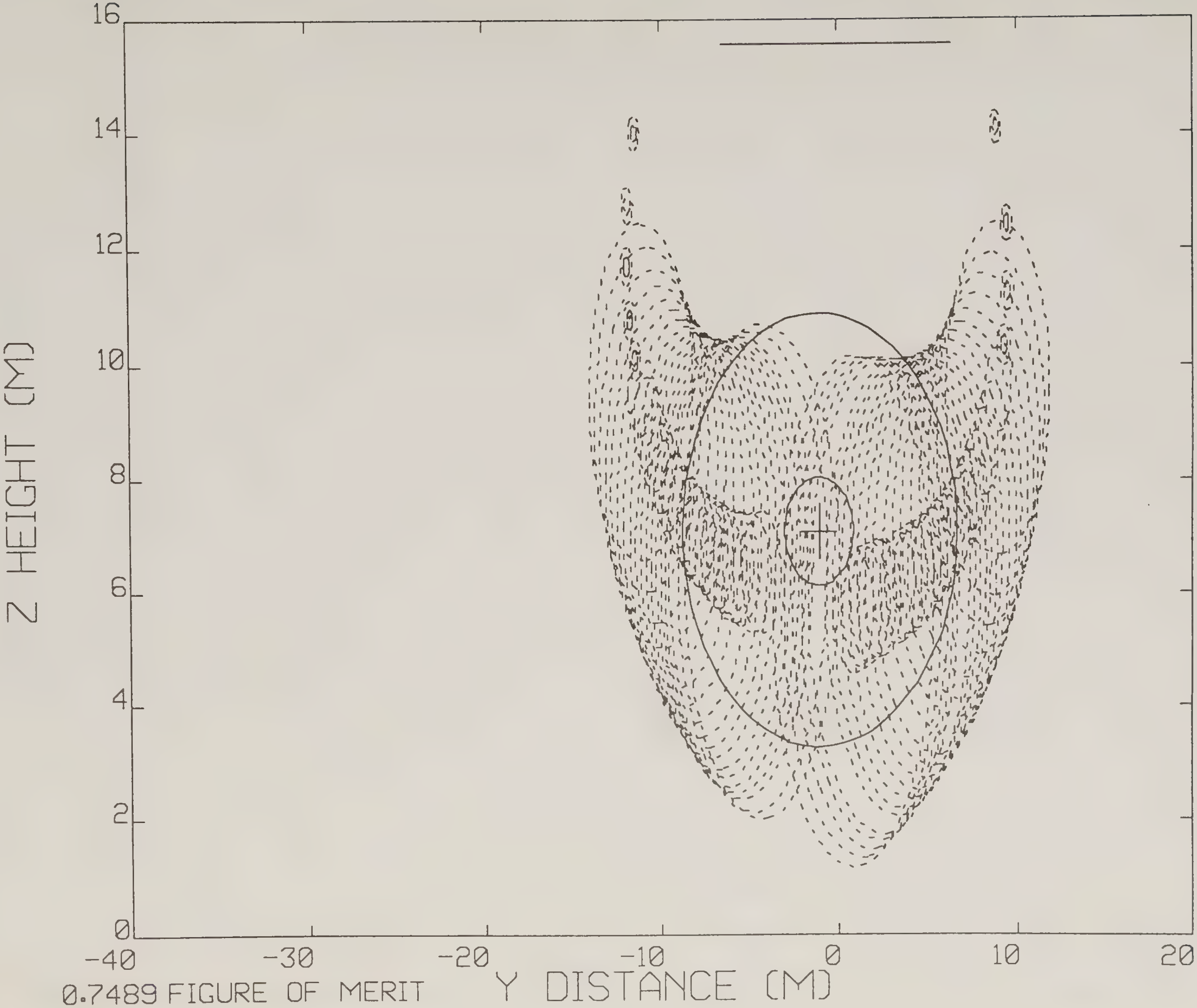

Figure 6-16 Equivalent Gaussian distribution for Example Case 3. The corresponding figure of merit is also displayed.

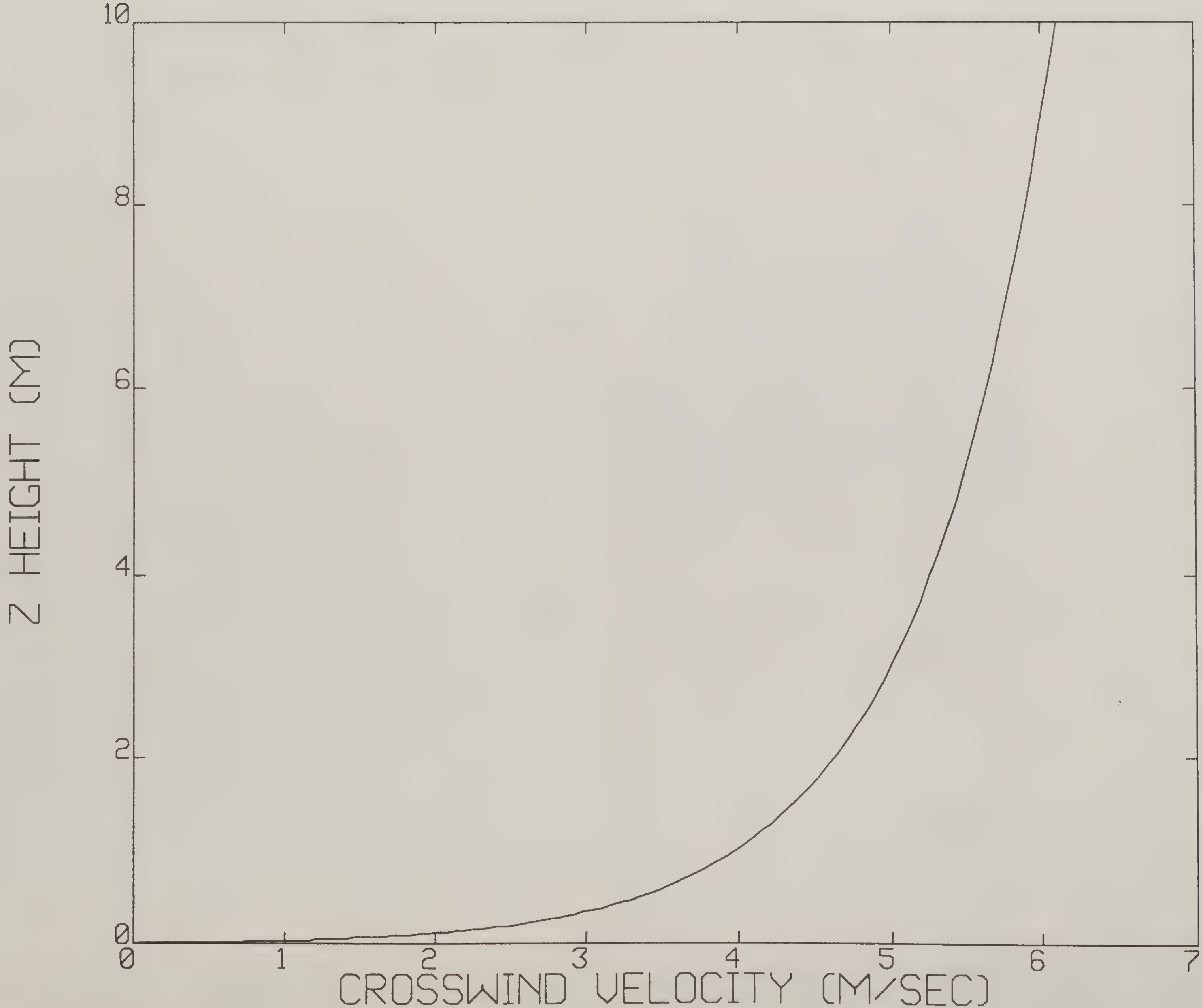

Figure 6-17 Crosswind velocity profile for Example Case 3.

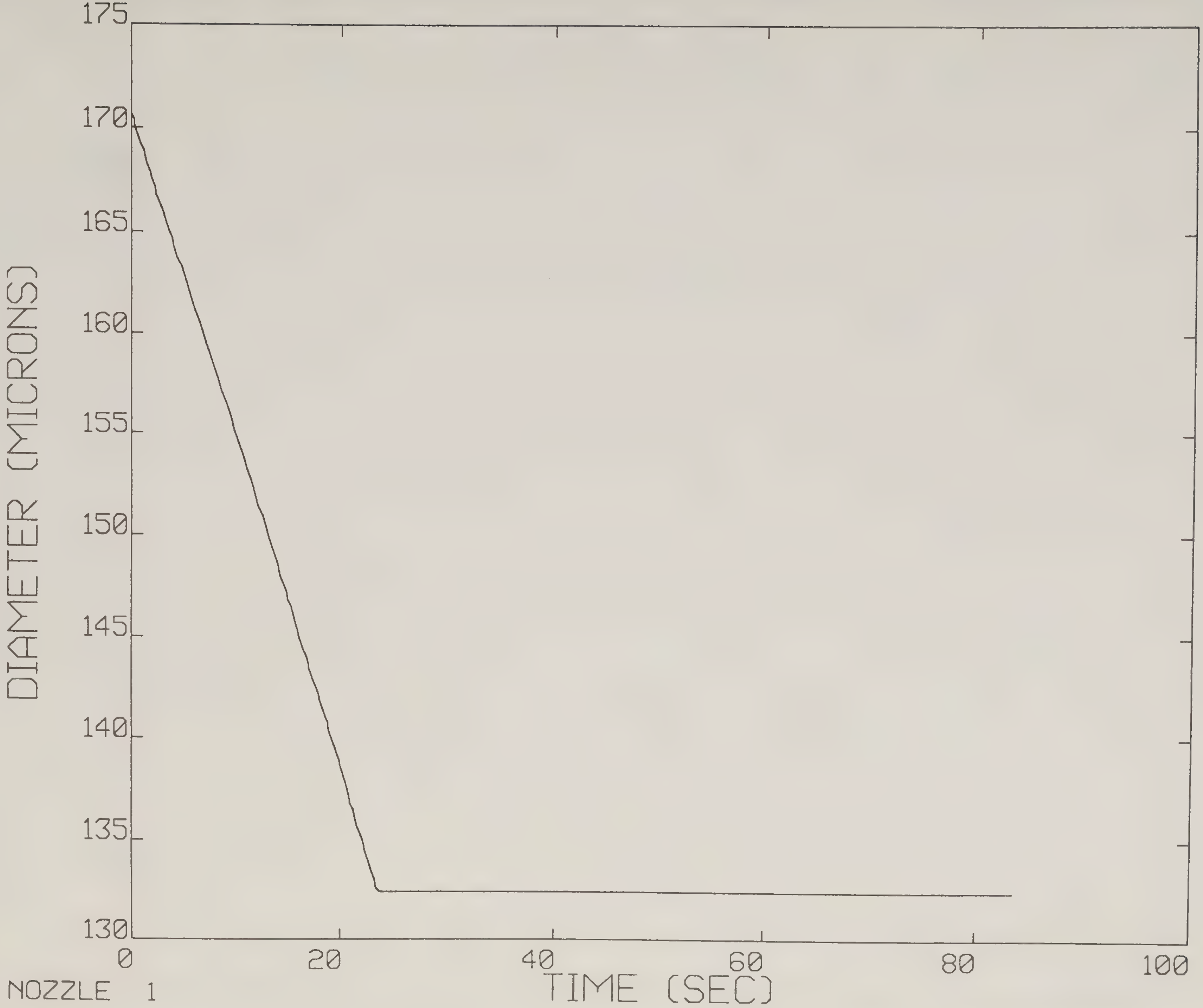

Figure 6-18 Diameter time history for material from the first nozzle in Example Case 3. Evaporation is nearly linear down to the nonvolatile diameter.

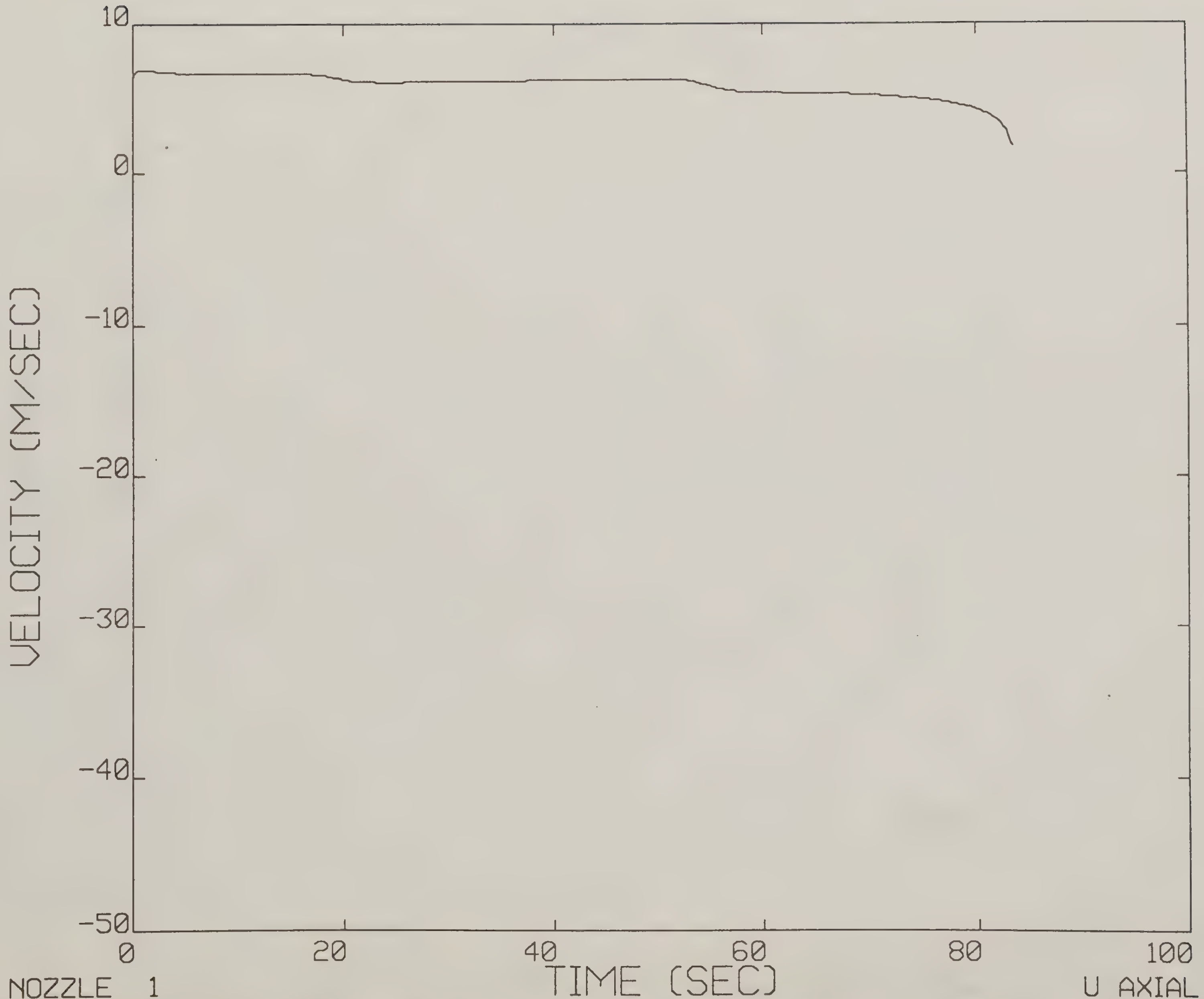

Figure 6-19 U axial velocity time history for material from the first nozzle in Example Case 3. Material is released at the aircraft speed (49.6 m/sec on card 0020 in Figure 6-9) and quickly adjusts to the background speed (from card 0028 in Figure 6-9) until the drop approaches the ground.

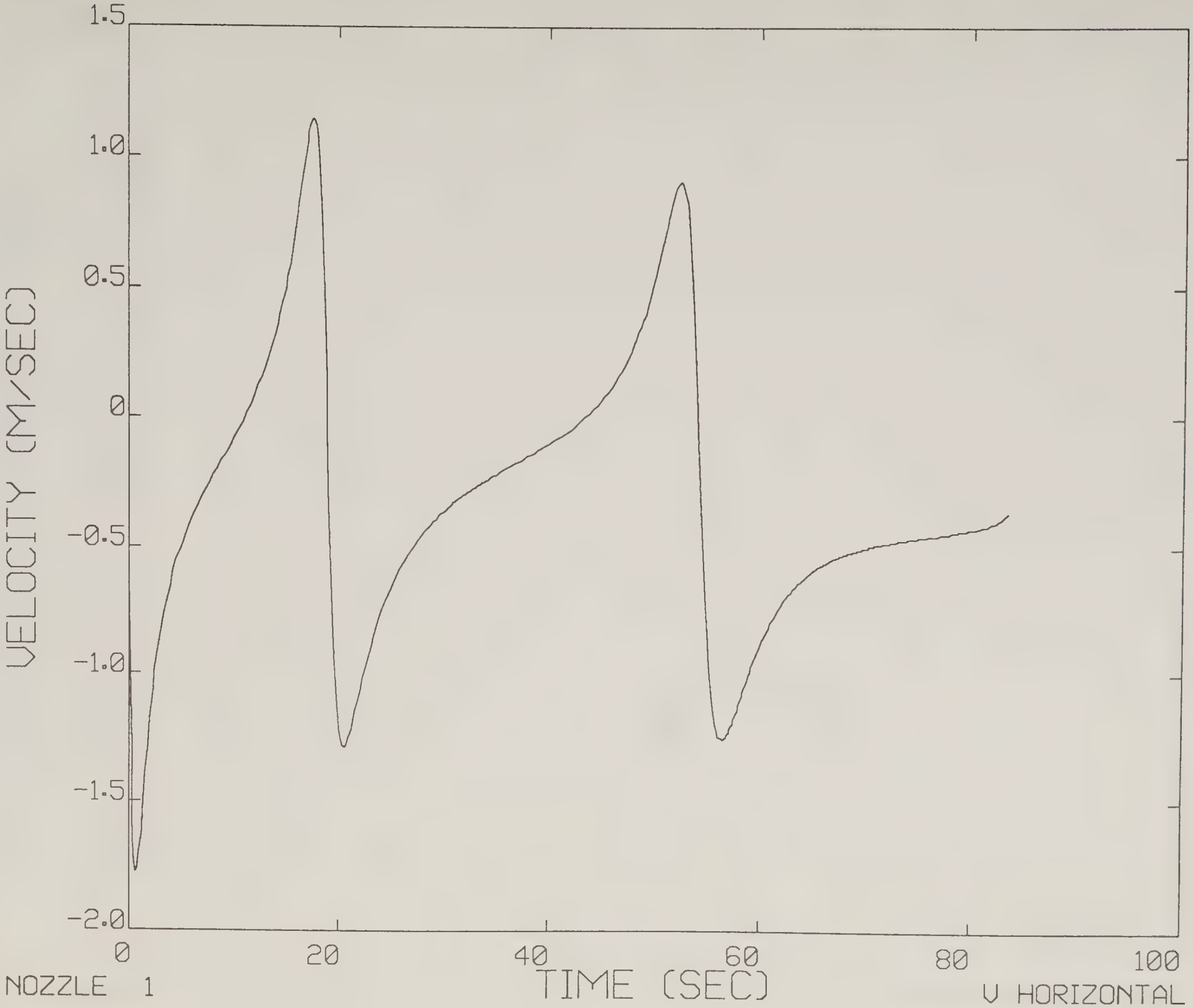

Figure 6-20 V horizontal velocity time history for material from the first nozzle in Example Case 3. The drop is caught in the left tip vortex (as seen in Figure 6-10).

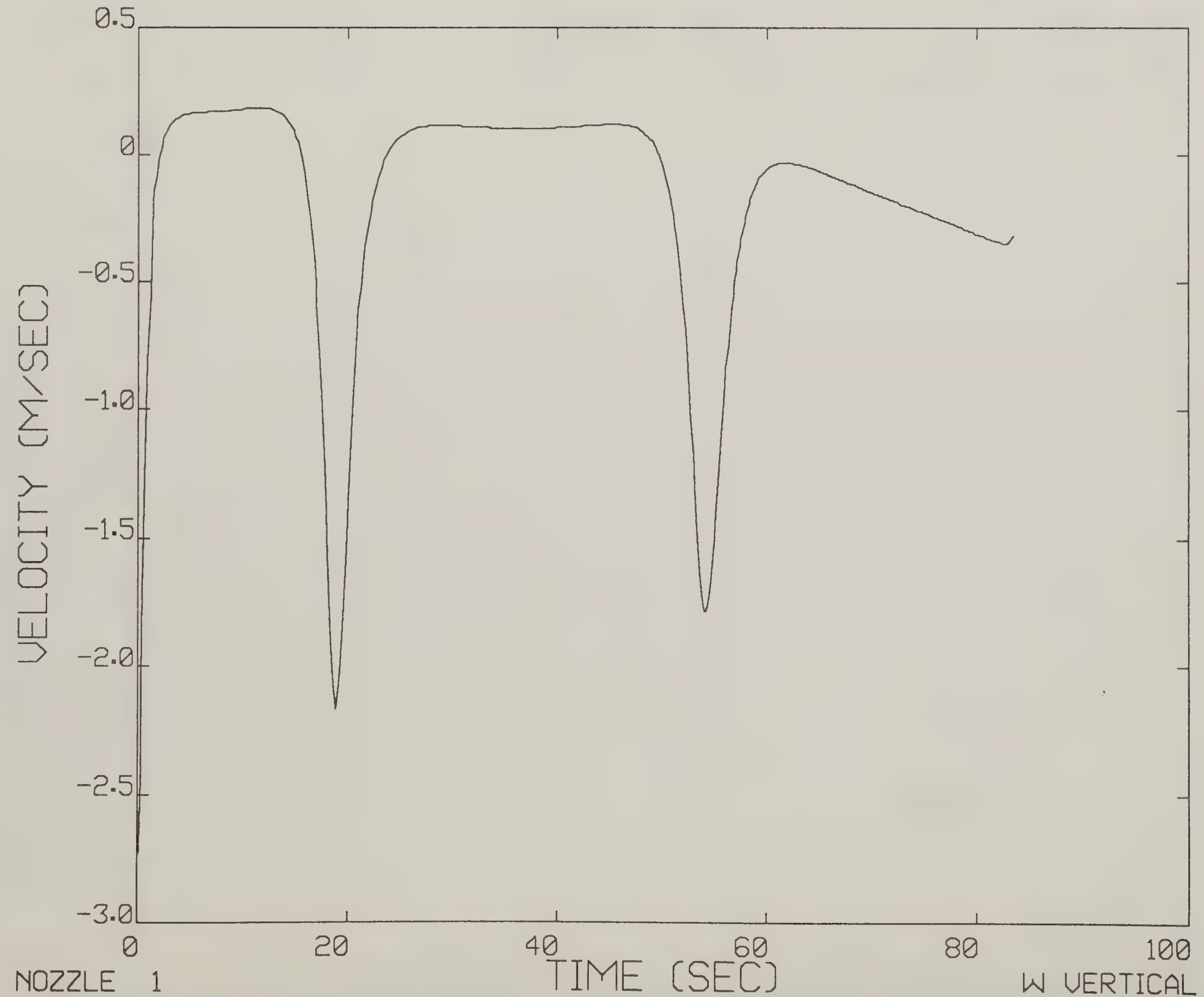

Figure 6-21 W vertical velocity time history for material from the first nozzle in Example Case 3. The drop is caught in the left tip vortex (as seen in Figure 6-10).

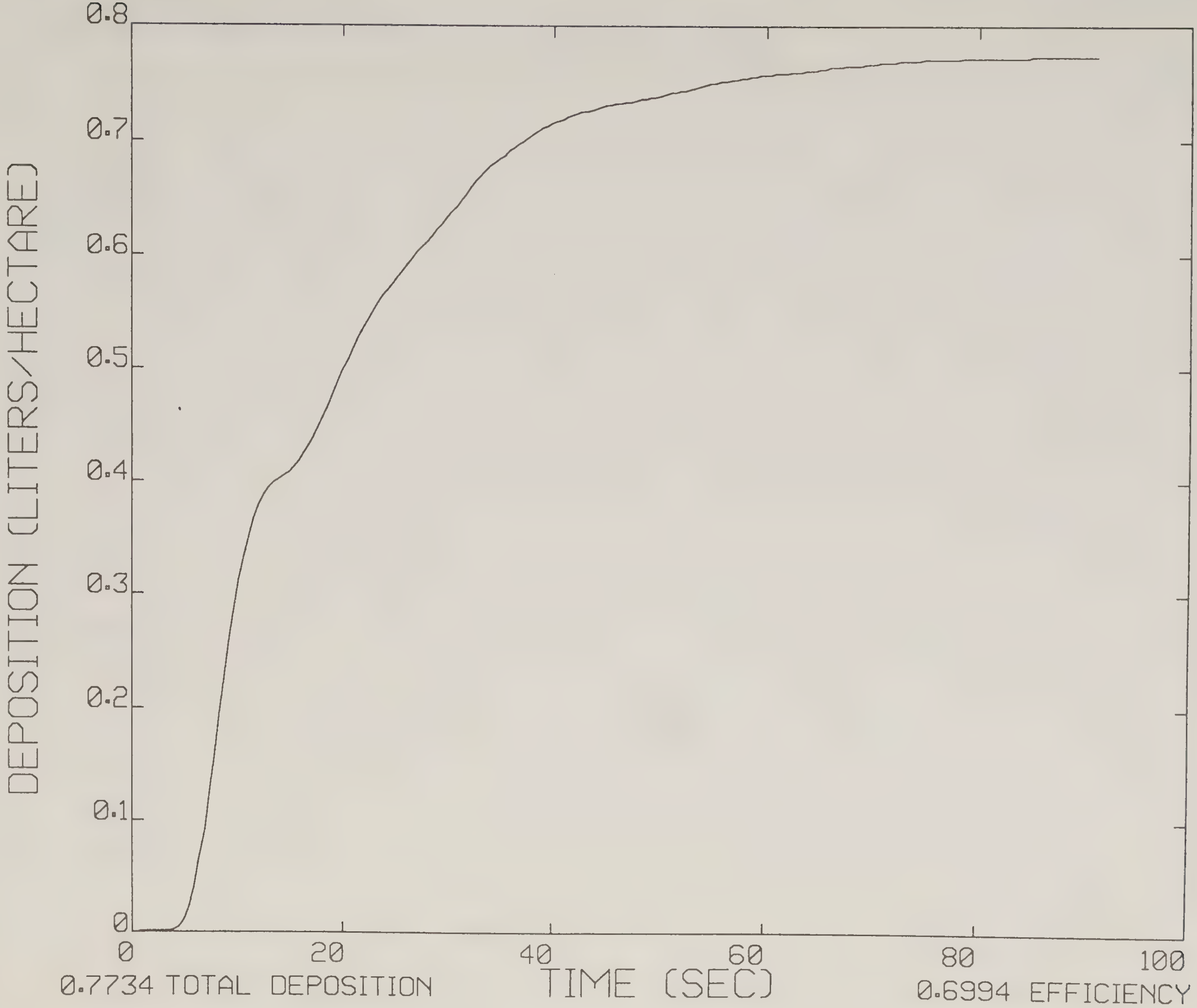

Figure 6-22 Deposition on the upstream side (-1,0,0) of a 0.075 meter diameter sphere placed in the Example Case 3 flow field at y = - 10 meters and z = 2 meters. The target collection efficiency and final deposition level are also displayed.

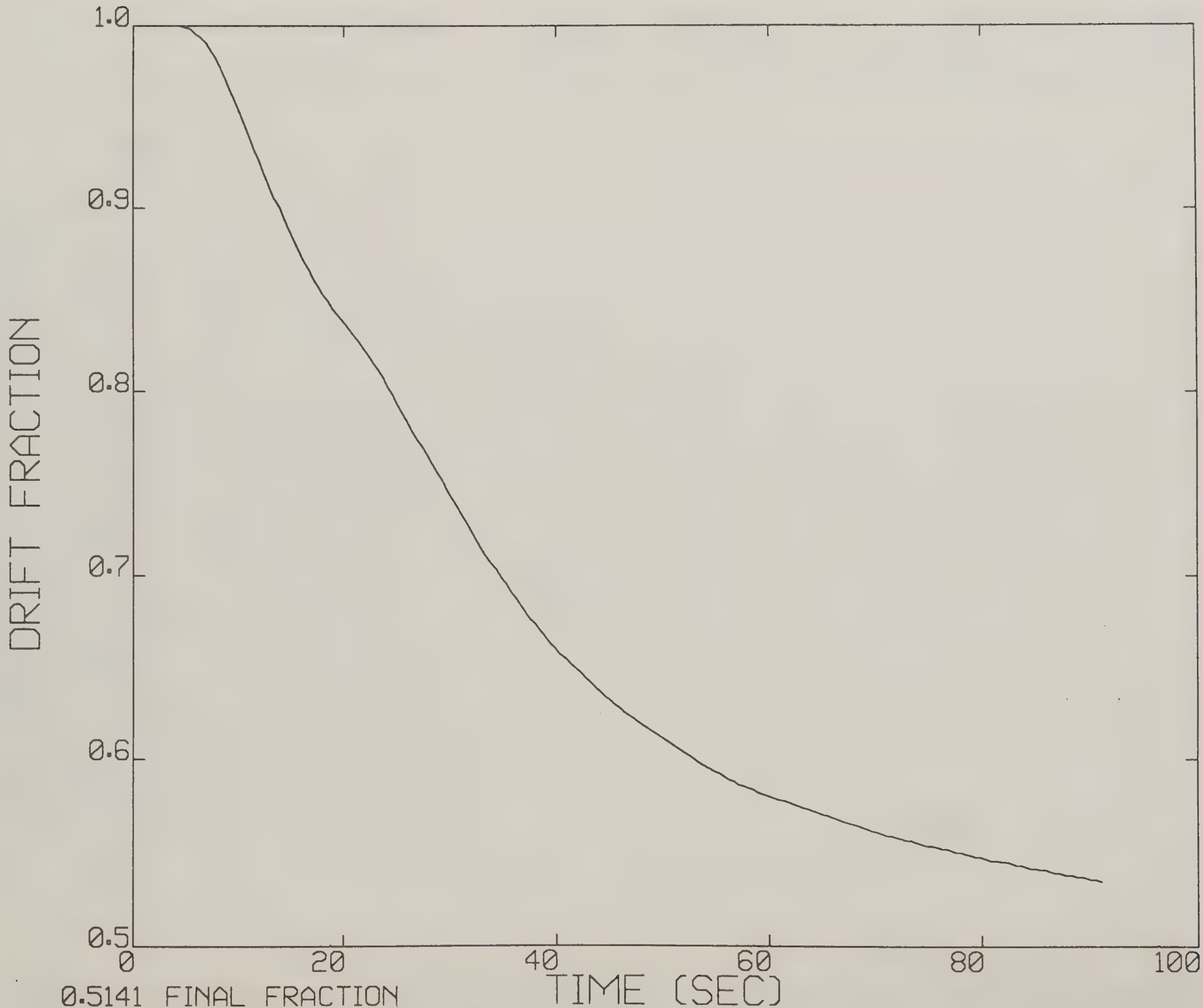

Figure 6-23 Drift fraction for all material released in Example Case 3. The final fraction of material that remains drifting is also displayed. Figure 6-9 (card 0065) indicates that a volatile fraction of 0.536 may evaporate.

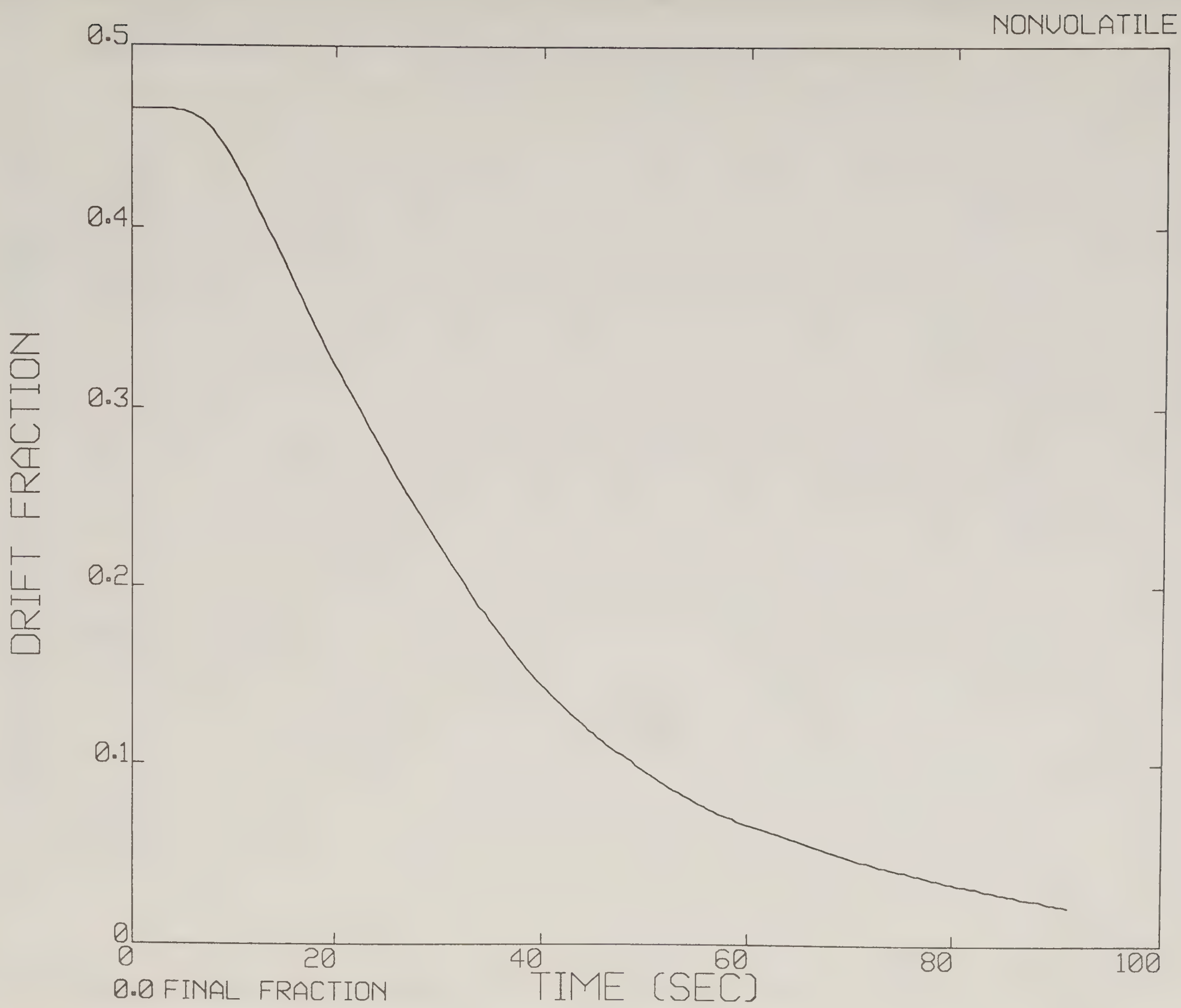

Figure 6-24 Drift fraction of nonvolatiles in Example Case 3. Figure 6-9 (card 0065) indicates that the nonvolatile fraction of released material is 0.464.

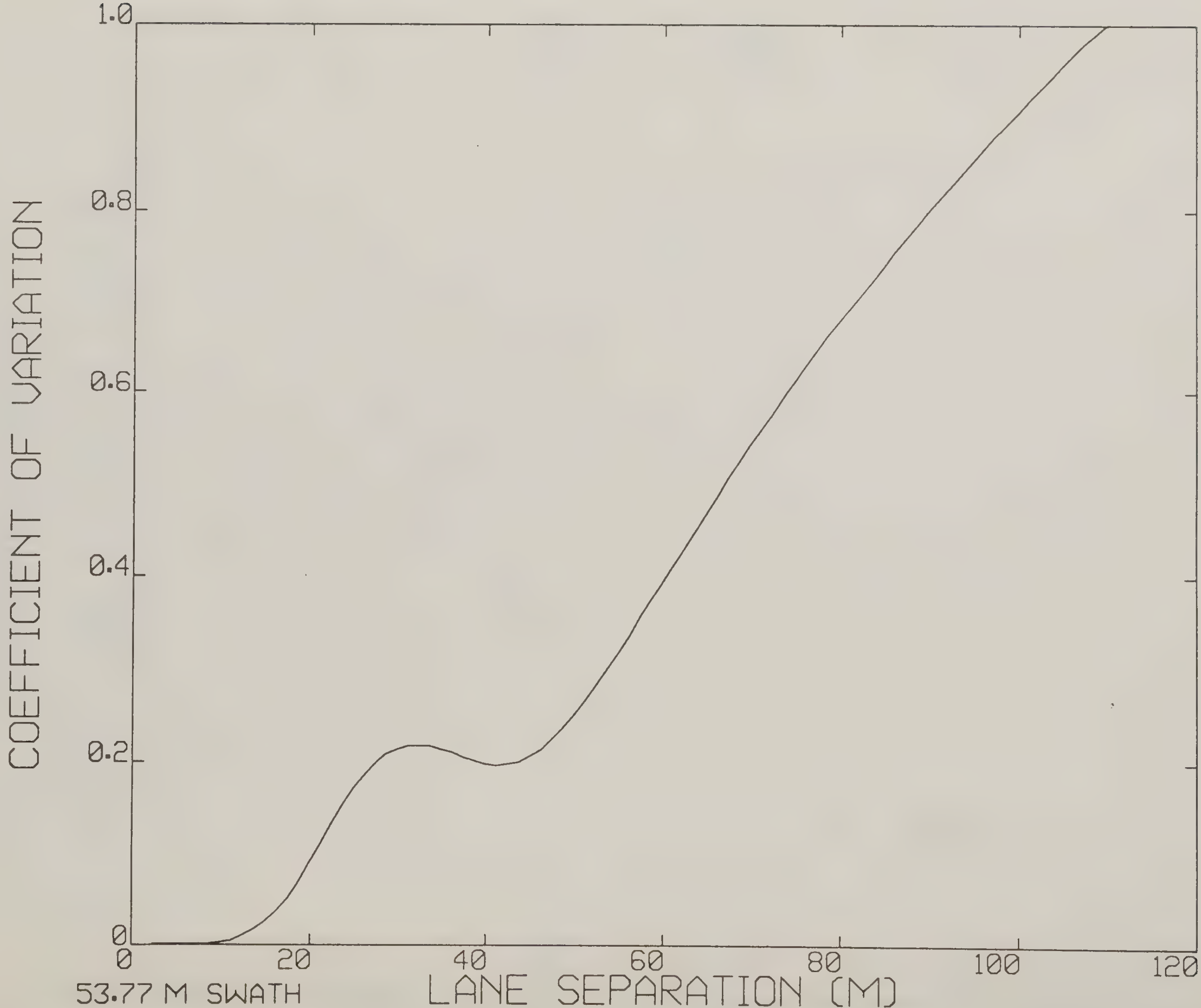

Figure 6-25 Coefficient of variation for the continuous ground deposition in Example Case 3. For a typical value of 0.3 (Teske, Twardus and Ekblad 1990), the ideal lane separation between aircraft flight lines is approximately 54 meters.

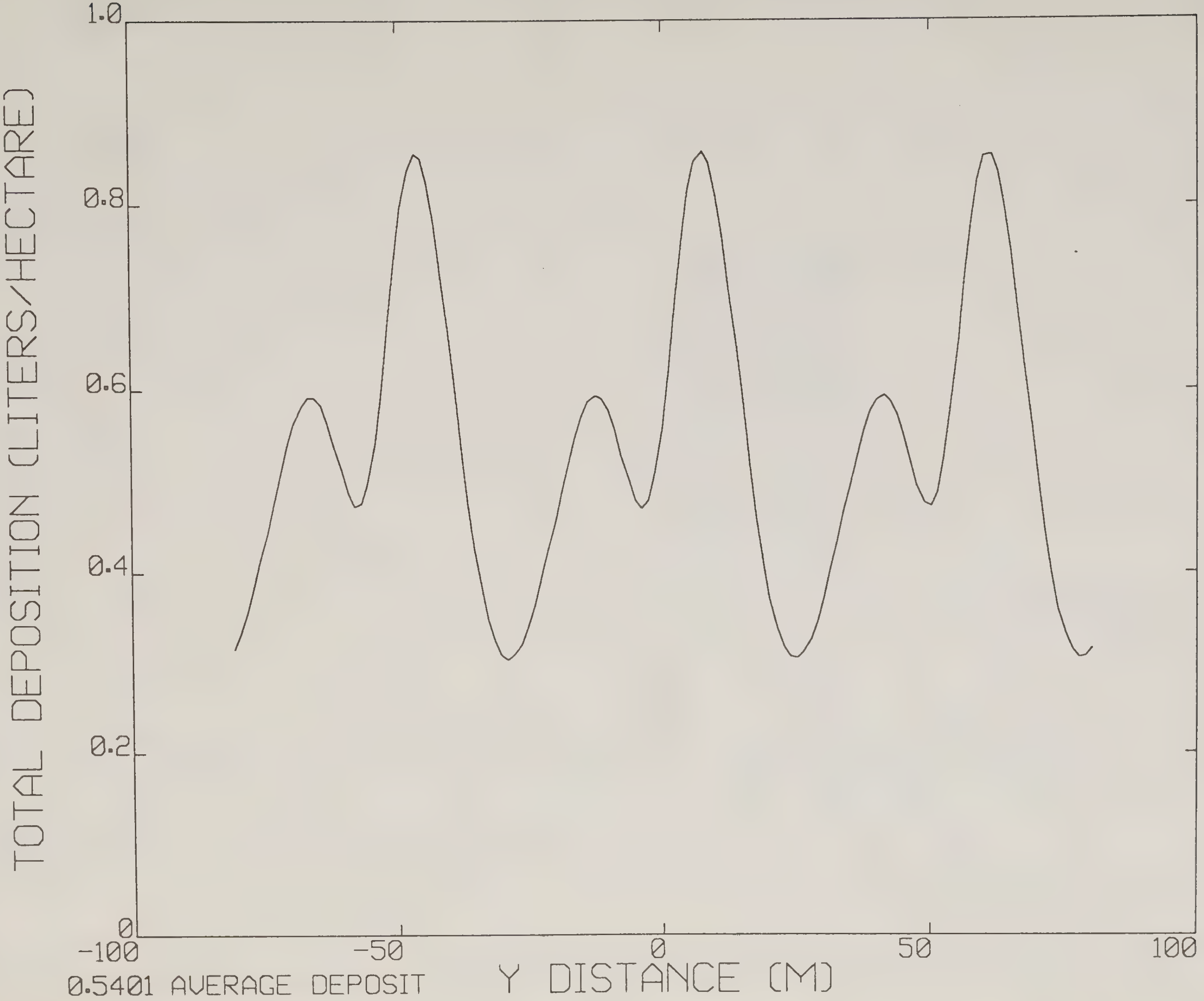

Figure 6-26 Overlapped swath deposition pattern for Example Case 3, with a lane separation of 53.77 meters as suggested in Figure 6-25.

```
0000   HILLER 12E
0010   50.0
0011   100  0  0  1
0020   4  5.4  14.20  11.09
0029    0.0  0.0       0.0
0029    1.0  0.0379  -0.0379
0029    2.0  0.0758  -0.0758
0029    5.0  0.1895  -0.1895
0029    7.3  0.2767  -0.2767
0029   10.0  0.3323  -0.3323
0029   12.0  0.3668  -0.3668
0029   15.0  0.4111  -0.4111
0030   10325.0  400.0
0050   0  0.0
0055   0.0  0.044
0055   0.6  0.044
0055   1.8  0.147
0055   3.1  0.221
0055   4.3  0.191
0055   5.5  0.150
0055   6.7  0.074
0055   7.3  0.0
0056   0.2
0060   28  0.0  0.0  1.0  2.8
0061   -4.12  -2.0
0061   -3.81  -2.0
0061   -3.51  -2.0
0061   -3.20  -2.0
0061   -2.90  -2.0
0061   -2.59  -2.0
0061   -2.29  -2.0
0061   -1.98  -2.0
0061   -1.68  -2.0
0061   -1.37  -2.0
0061   -1.07  -2.0
0061   -0.76  -2.0
0061   -0.46  -2.0
0061   -0.15  -2.0
0061    0.15  -2.0
0061    0.46  -2.0
0061    0.76  -2.0
0061    1.07  -2.0
0061    1.37  -2.0
0061    1.68  -2.0
0061    1.98  -2.0
0061    2.29  -2.0
0061    2.59  -2.0
0061    2.90  -2.0
0061    3.20  -2.0
0061    3.51  -2.0
0061    3.81  -2.0
0061    4.12  -2.0
0064  251.0   1.0
```

Figure 6-27 AGDISP input file for Example Case 4.

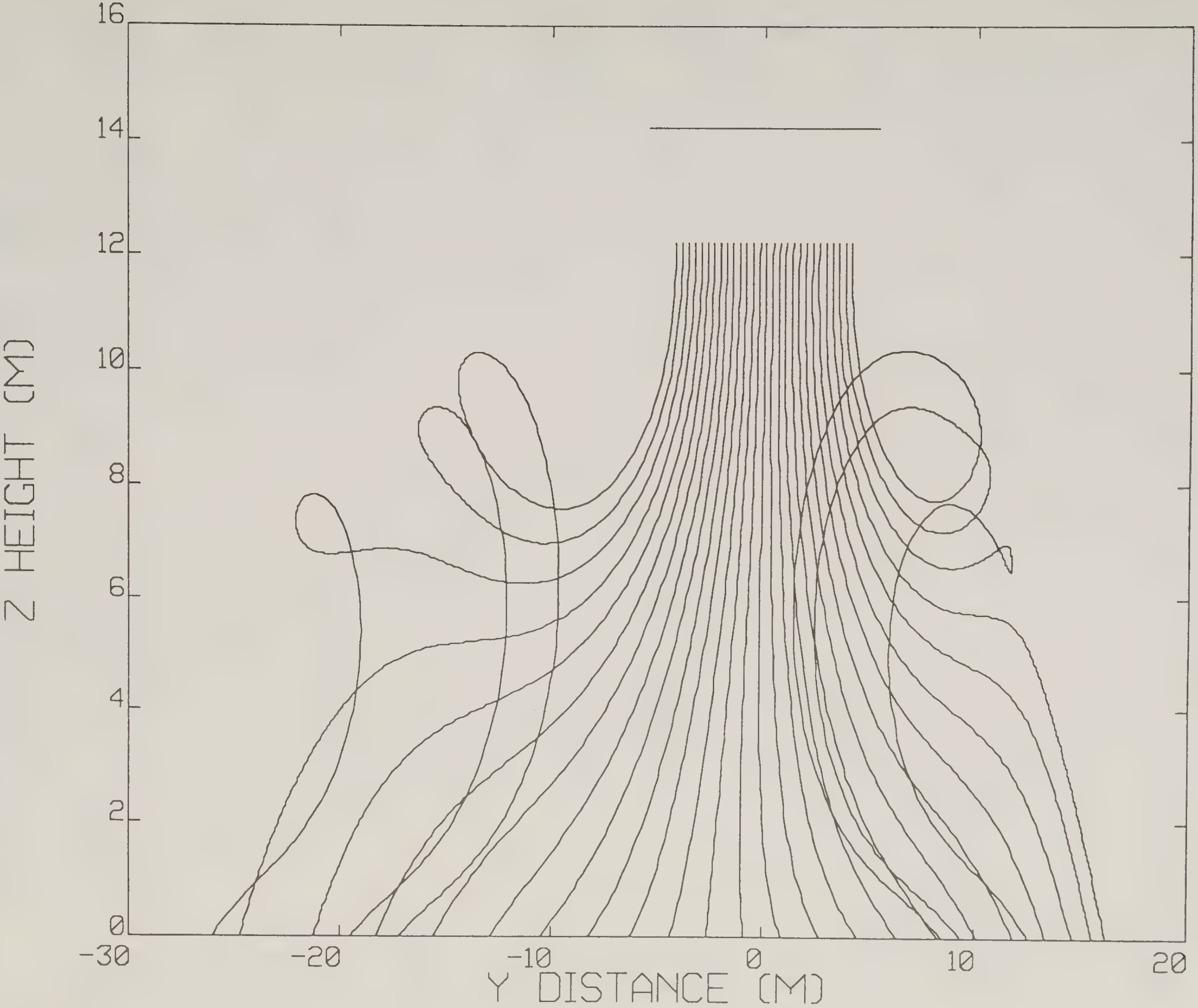

Figure 6-28 Mean trajectories for Example Case 4.

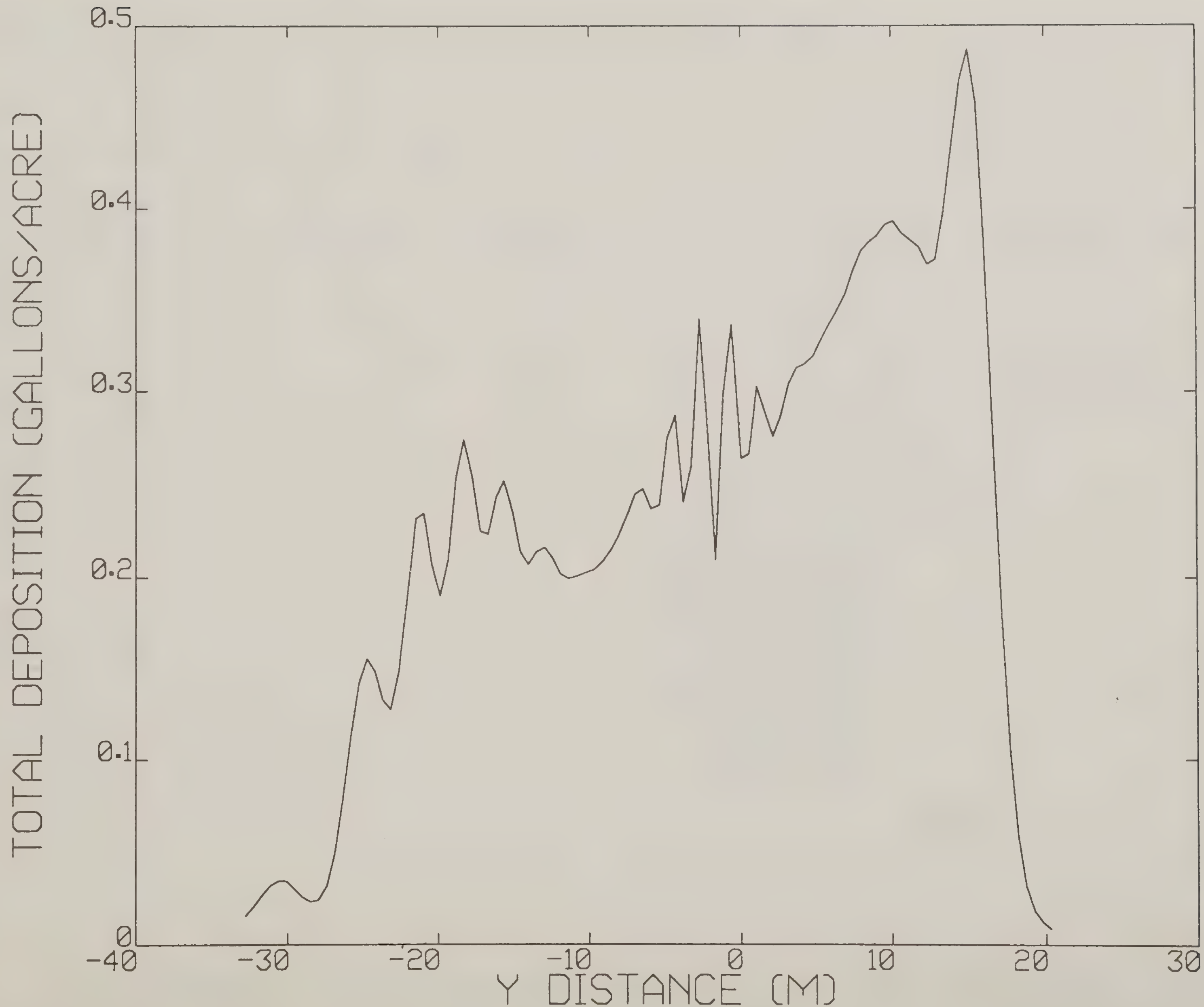

Figure 6-29 Continuous ground deposition for Example Case 4.

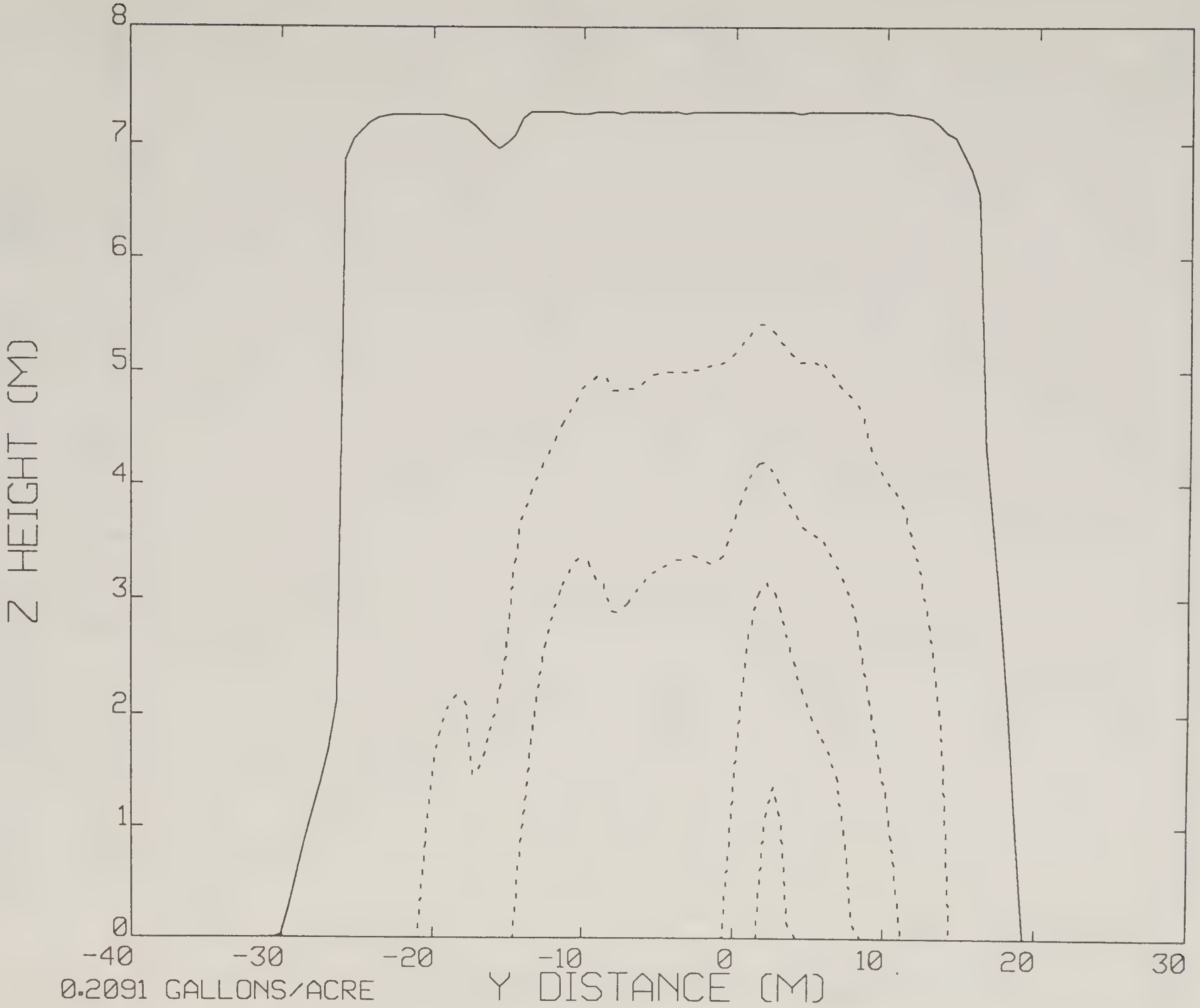

Figure 6-30 Canopy deposition contours for Example Case 4. The near-zero contour is shown as solid, and the dashed contours are for 0.05, 0.1, 0.15 and 0.2 gallons per acre. The maximum deposition is also displayed.

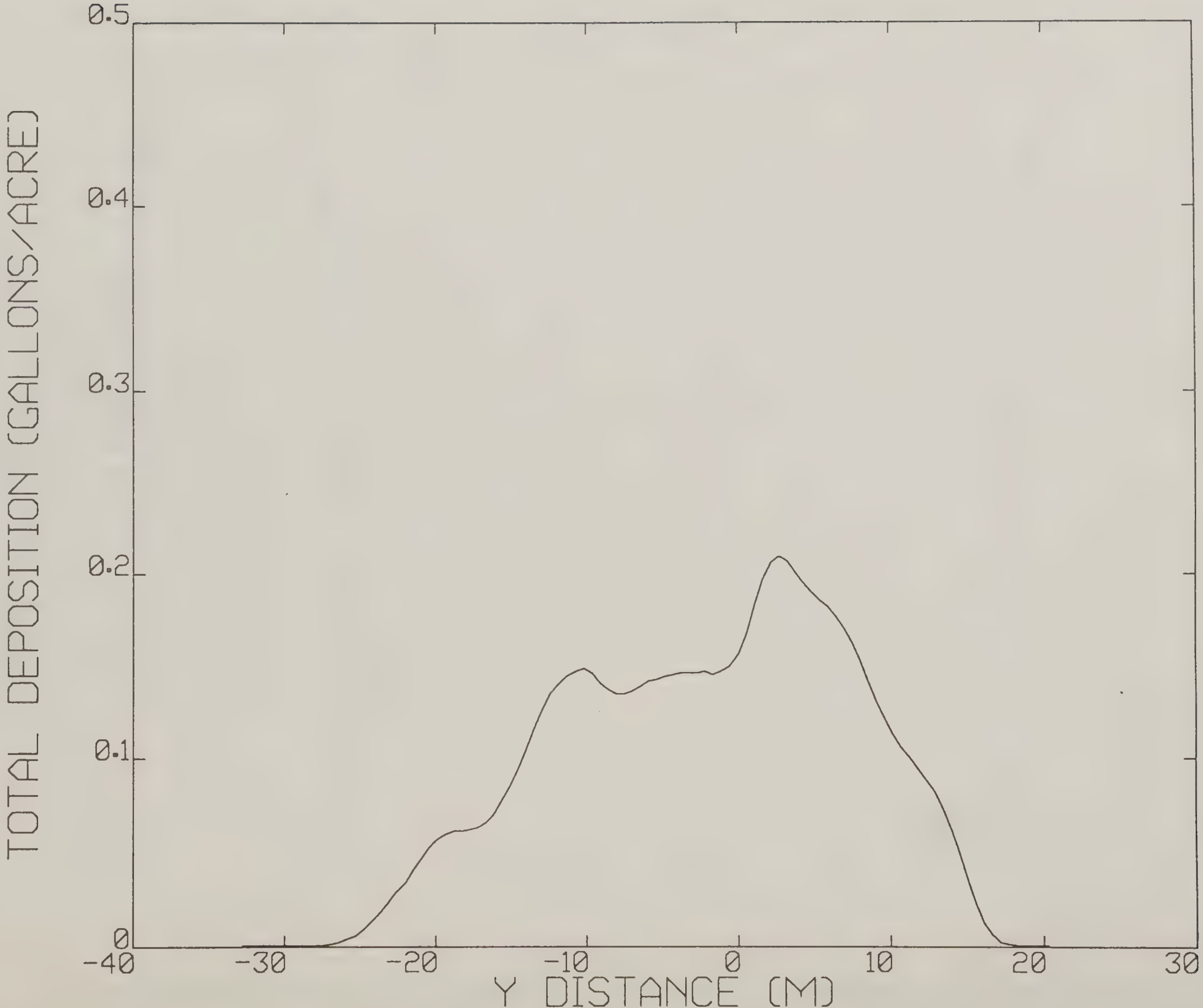

Figure 6-31 Total canopy deposition for Example Case 4.

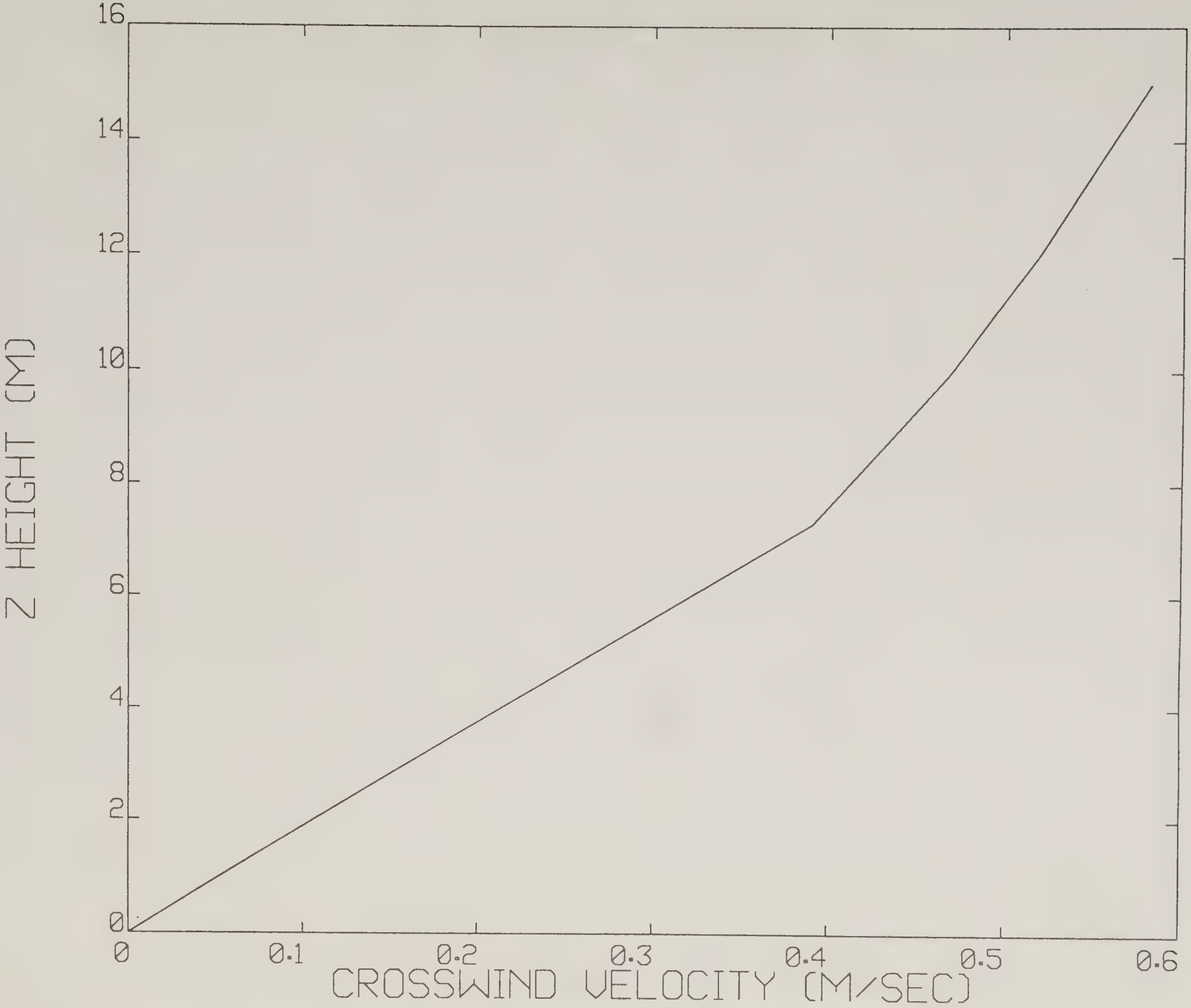

Figure 6-32 Crosswind velocity profile for Example Case 4. The canopy extends to a height of 7.3 meters (from cards 0055 in Figure 6-27); within the canopy the velocity is assumed linear.

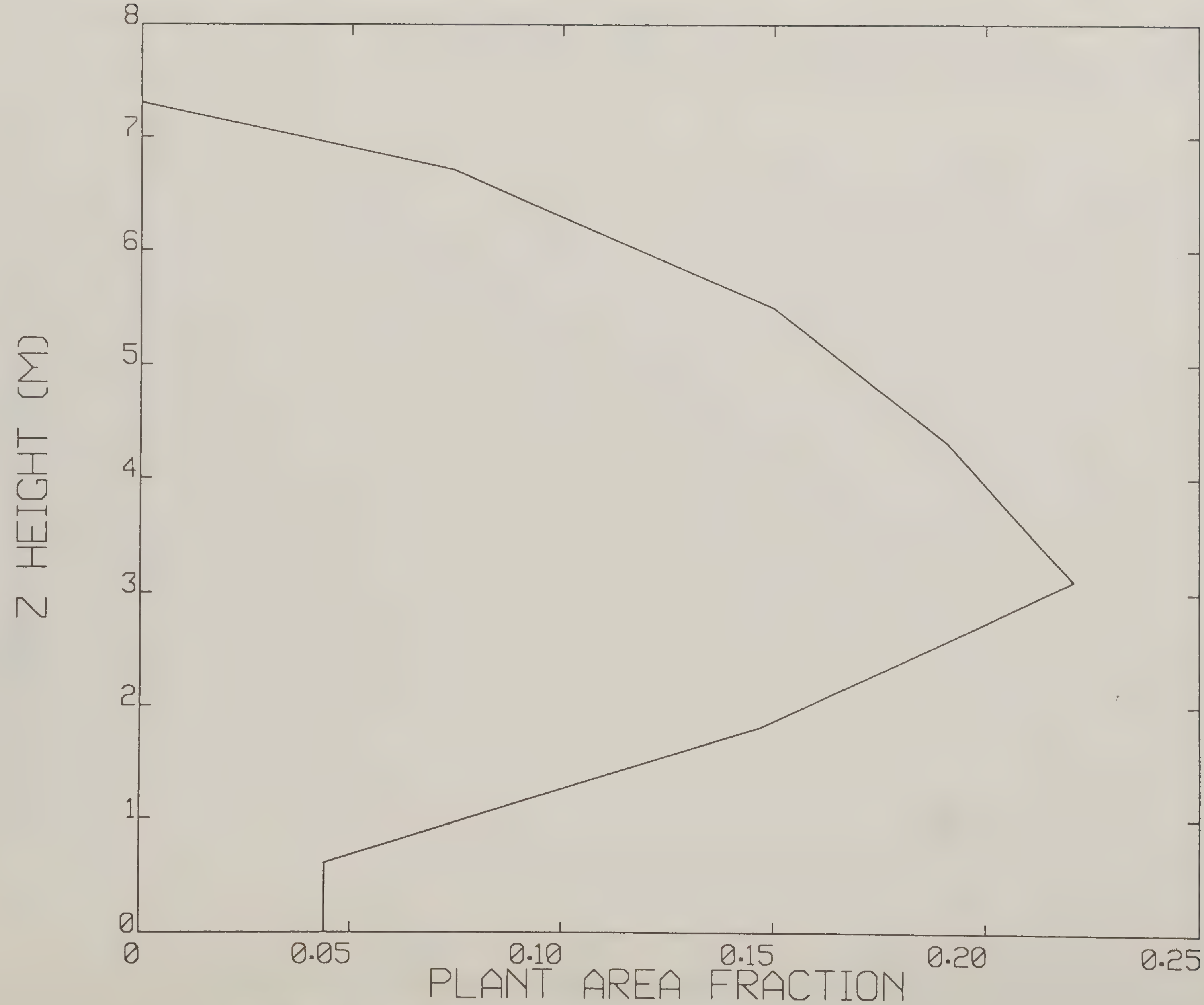

Figure 6-33 Plant area fraction profile for Example Case 4.

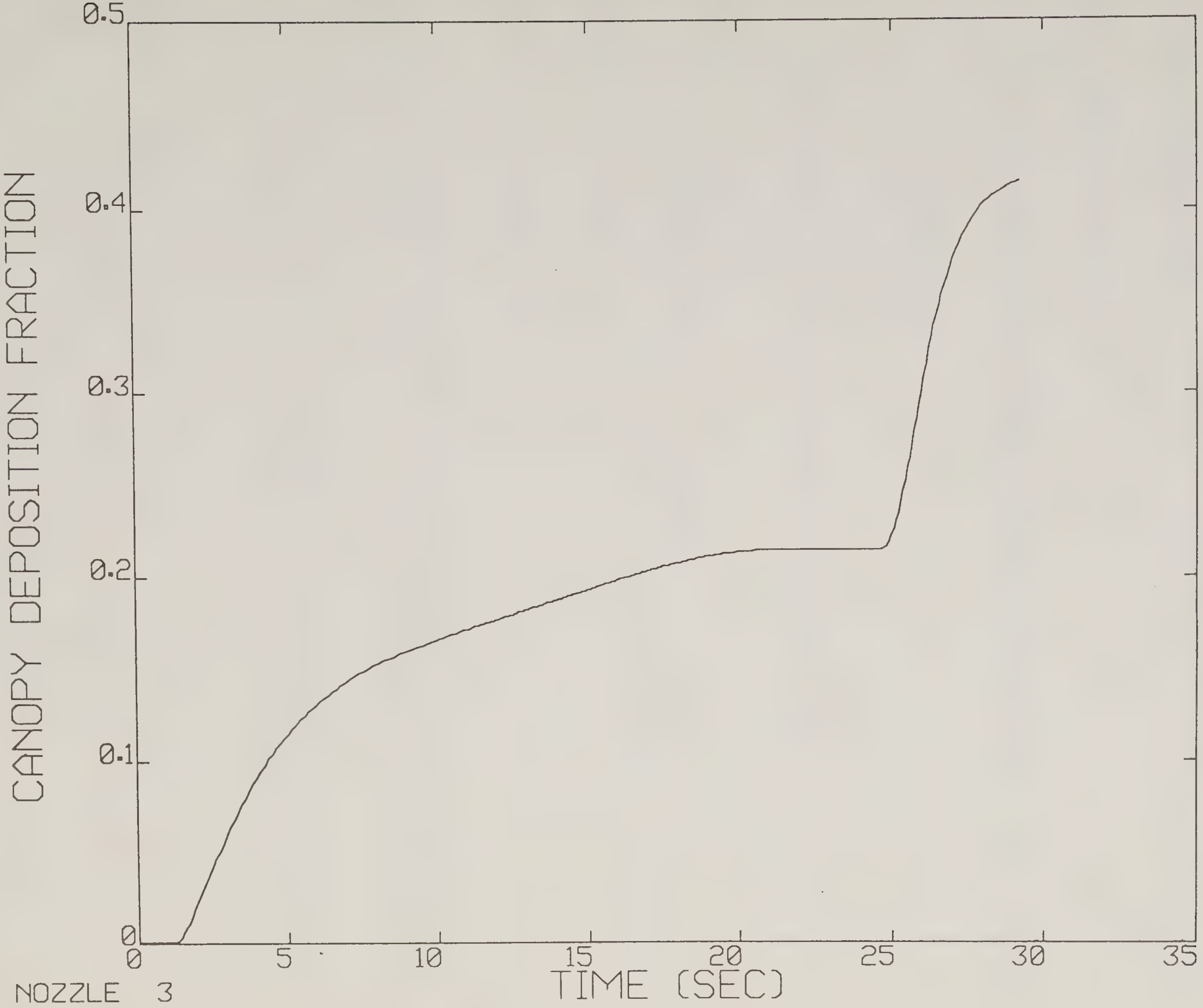

Figure 6-34 Canopy deposition fraction for material from the third nozzle in Example Case 4.

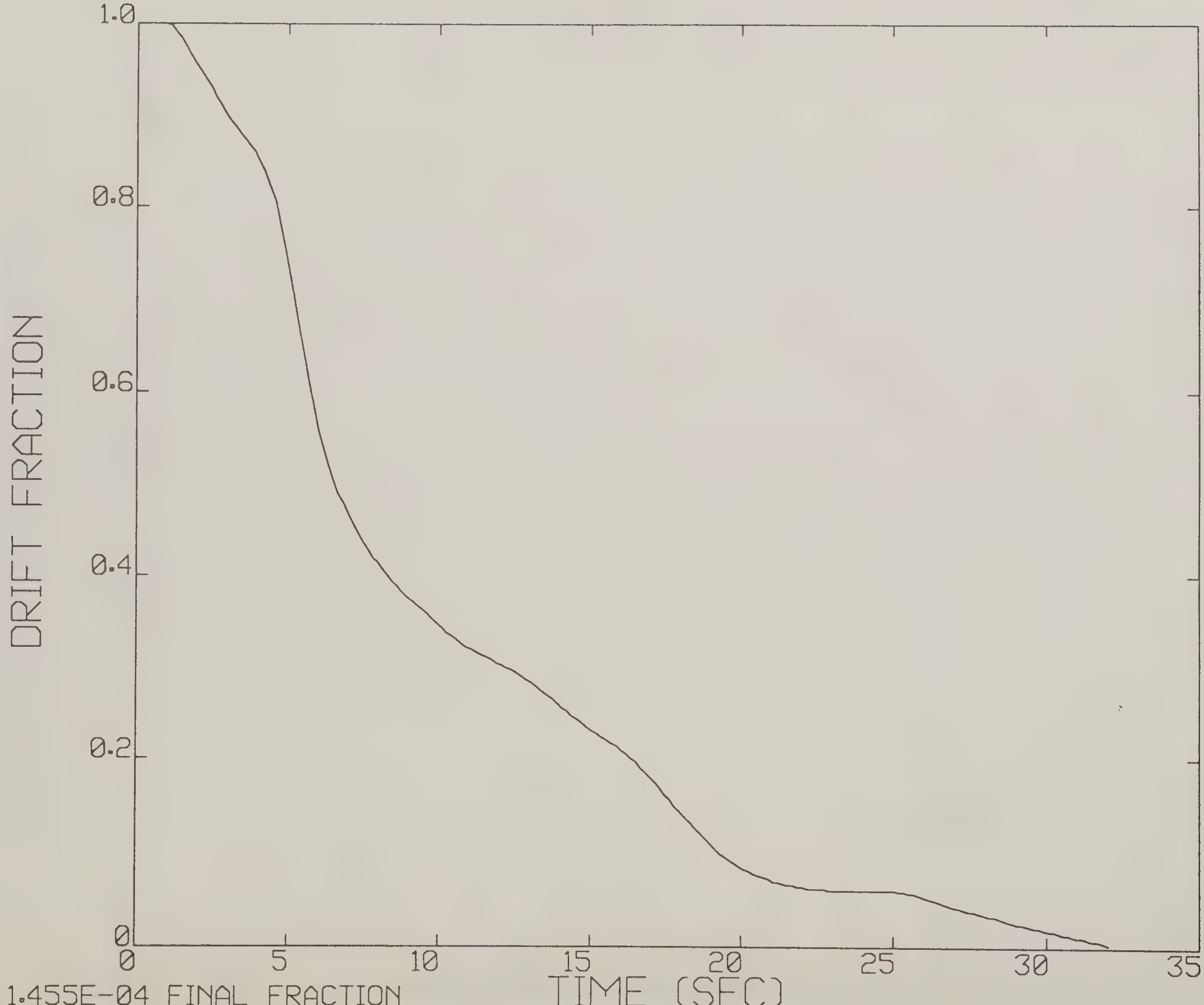

Figure 6-35 Drift fraction for Example Case 4.

7. AGDISP Operation on Mainframe Computers

The latest versions of AGDISP and AGPLOT are operational on two mainframe computer systems.

DATA GENERAL MV-15000

AGDISP and AGPLOT are run on the Data General Forest Service network by the commands

XEQ AGDISP

XEQ AGPLOT

with resolution of the filenames and extensions performed within the programs. Both programs will ask

Enter MASTER filename

to enter the filename of the input file to the programs.

The plotting package GKS is invoked to plot AGPLOT results onto user-selected graphics output devices.

DIGITAL EQUIPMENT VAX

AGDISP and AGPLOT may both be invoked by command files of the form shown on Table 7-1. Input on a file named FILENAME.INP will produce a binary log file FILENAME.LOG that controls all saved plot information. The printer file AGDISP.LIS is created during AGDISP operation.

Plotting is accomplished by calls directly to a Tektronix 4025, saving these calls in an ASCII-readable file AGPLOT.PLT for later display by site-specific graphics programs.

TABLE 7-1

Command Procedures for AGDISP on VAX

To Invoke AGDISP: `@AGDISP FILENAME`

will generate

```
$ASSIGN/NOLOG  FILENAME.INP  FOR004
$ASSIGN/NOLOG  CASEFILE.INP  FOR007
$ASSIGN/NOLOG  AGDISP.LIS    FOR009
$RUN AGDISP
```

To Invoke AGPLOT: `@AGPLOT FILENAME`

will generate

```
$ASSIGN/NOLOG  FILENAME.LOG  FOR012
$ASSIGN/NOLOG  AGPLOT.PLT    FOR015
$ASSIGN/USER   SYS$COMMAND   SYS$INPUT
$RUN AGPLOT
```

8. AGDISP Operation on Personal Computers

A series of additional programs have been written to make the use of AGDISP and AGPLOT more straightforward on personal computers. These programs are described below and illustrated in the flowchart shown in Figure 8-1.

AGEDIT

AGEDIT is a simple full-screen editor that permits the set up and modification of AGDISP input files. It contains a built-in Help facility that briefly explains every input card type currently available in AGDISP.

AGEDIT is invoked with the command

AGEDIT filename

If a file name is not entered on the command line, AGEDIT asks

Enter AGDISP Input File To Edit

The Help facility must be available to AGEDIT or the message is

AGHELP.DOC Cannot Be Found Or Opened

If the INP file given the program cannot be found, AGEDIT assumes the file is to be created rather than modified.

Active function keys are the following:

F1 Switches to the Help file and back, displaying information about the current card pointer. Once in Help, movement is up (back to screen 1 -- the information screen) or down (to the last screen) with the up and down cursor arrow keys.

F2 Switches to the Menu options screen.

While editing, a brief Help line is always present on the screen; this line displays any identifiable card number and the names/number of variables that should be on the card. If the card is not recognizable, AGEDIT displays

Unsupported AGDISP Card

The editing options available are the following:

1 The cursor keys (arrow keys) allow movement up, down, left and right in the file.

2 Typing any realistic characters are added at the current cursor position.

3 INSERT may be toggled on (to insert the characters typed) or off (to overwrite with the characters typed).

4 DELETE or BACKSPACE deletes the character to the left of the present cursor position.

5 ENTER generates a new line in the file.

6 HOME moves to the first character in the current line.

7 END moves to the last character in the current line.

The menu options available are the following:

0 Exit/Edit Without Saving Changes

AGEDIT always verifies program exit with

Exit (N/Y)

The response must be Yes; otherwise AGEDIT returns to editing.

1 Save Results In Existing File And Exit

AGEDIT saves any editing changes in the current input file and exits.

2 Save Results In New File And Exit

AGEDIT asks

Enter New AGDISP Input File

and then saves the editing session into this file (with the extension INP) and exits. Once back to AGCTRL, the master input file may be changed to the new AGDISP input file before running AGDISP.

3 Recover Aircraft Characteristics From Database

AGEDIT contains access logic to FSCBG.ACL, the complete aircraft library from Hardy 1987 corrected by B. Thompson and B. Kirk (private communication). If the binary data file cannot be located, AGEDIT writes

FSCBG.ACL Cannot Be Found Or Opened.
Press Any Key To Continue ...

after which AGEDIT returns to editing.

Five aircraft types are shown on the screen at a time. Movement through the aircraft library is with the up and down cursor arrow keys. The selection of a specific aircraft type is made by positioning the highlight line on the desired aircraft type and pressing the ENTER key. The menu option may be aborted with the F1 function key.

When an aircraft type is selected, the pertinent data is tranferred into the edited file. Inappropriate cards are removed. If the English units card 0001 is present in the edited file, the units will be adjusted from their default MKS values. The aircraft is assumed to be flying at a height of 10.0 units (meters or feet); the actual height must be corrected after aircraft characteristics are transferred to the edited file.

4 Recover Drop Size Distribution From Database

AGEDIT also contains access logic to FSCBG.MSL, the complete drop size distribution library from Skyler and Barry 1990. If the binary data file cannot be located, AGEDIT writes

FSCBG.MSL Cannot Be Found Or Opened.
Press Any Key To Continue ...

after which AGEDIT returns to editing.

Five drop size descriptions are shown on the screen at a time. Movement through the drop size distribution library is with the up and down cursor arrow keys. The selection of a specific drop size distribution is made by positioning the highlight line on the desired description and pressing the ENTER key. The menu option may be aborted with the F1 function key.

When a drop size distribution is selected, the pertinent data is tranferred into the edited file. Inappropriate cards are removed. FSCBG.MSL contains complete drop size distributions that have been combined by pairs if more than 16 drop sizes were originally present.

5 Recover Drop Size Distribution From SDC Savefile

AGEDIT permits the importing of drop size distribution information from DROPSIZE (Teske 1990b) and SDC (Teske 1989d) with the message

Enter SDC Savefile FILENAME.EXT

If the file cannot be located, AGEDIT returns to editing. Otherwise, it opens the file, assumes it is in SDC file format, and reads and transfers drop size distribution data to the edited file. Only the first 16 drop sizes are transferred to the edited file.

6 Compute Wet Bulb Temperature Depression

AGEDIT contains a simplification of the WETBULB program (explained below) by computing the wet bulb temperature depression (for card 0065) with the following entries

Enter Dry Bulb Temperature

Enter Relative Humidity

Temperature is deg C unless card 0001 is present in the edited file; then the temperature is deg F. Relative humidity is in percentage. Sea-level pressure is assumed. Results are computed and entered on card 0065 with a volatile

fraction of 0.875. The actual volative fraction must be corrected after the wet bulb temperature depression is transferred to the edited file.

In all cases, a return to the edited file places the cursor in the home position at the top of the file.

AGVIEW

AGVIEW presents the plotted results in a PLT file with the command

AGVIEW filename

If a file name is not entered on the command line, AGVIEW asks

Enter PLT File To View

If the entered PLT file cannot be found, the message is

filename.PLT Cannot Be Found Or Opened

The actual plots as sequentially produced in AGPLOT are:

1. First shown on the screen. Some of the titles and scales may appear scrunched because of the way the plot is presented.

2. Offered for transference to a printer attached to the computer by responding Yes to the question

   Hardcopy Previous Plot To Printer (N/Y)

AGVIEW works by reading specifications about the personal computer screen and the attached dot matrix printer from a default communications file called AGVIEW.DEF. If this file is not found, the message is

AGVIEW.DEF Cannot Be Found Or Opened

AGVIEW.DEF has a four-line default structure. For VGA screens and IBM/Epson printers it takes the form:

```
  11  0.749609
27,"3",24,27,"O".
27,"L",128,2.
27,"2".
```

Included on the distribution diskette is SAMPLE.PLT, a sample plot (Figure 8.2) that may be used to confirm screen and printer characteristics with the command

AGVIEW SAMPLE.PLT

The graphics information generated by AGPLOT and read by AGVIEW is written for display on a Tektronix 4025. On this terminal screen there are 640 pixels horizontally and 742 pixels vertically. Plots are constructed on their side. AGVIEW rotates the plots

ninety degrees for viewing on the screen, and keeps them on their side for plotting on the printer. All personal computer terminal screens have 640 pixels horizontally, but vary in vertical pixels:

CGA	200 pixels vertically
EGA	350 pixels vertically
VGA	480 pixels vertically

Details about the four lines in AGVIEW.DEF are as follows.

Line 1:

This line tells AGVIEW what type of screen the computer has and its resolution. The three default values currently on the market are:

CGA	2	0.311424
EGA	9	0.546166
VGA	11	0.749609

Lines 2, 3 and 4:

Every number (without quotation marks) and character (with quotation marks) is separated by a comma, and each line ends with a period. In this notation numbers are taken as ASCII values, to be invoked with the CHR$ function (the escape character is CHR$(27)), while characters are used as typed.

Line 2: 27,"3",24,27,"O".

IBM/Epson printers enter graphics mode with a command string

CHR$(27);"3";CHR$(N);

to specify the vertical movement of the paper per line. The "3" invokes spacing of N/216 inches, and in this application, the value of N is 24. Thus, the entire 742 pixels should be dot-matrix printed into a space equal to

$$(742/8) * (24/216) = 10.3 \text{ inches}$$

Changing the value of N modifies the appearance of the resulting plot.

The additional information on the second line

CHR$(27);"O";

turns off the page skip-over-perforation at the end of sixty lines. This option is necessary because of the length of the plot.

Line 3: 27,"L",128,2.

IBM/Epson printers enter the number of dots per line with a command string

CHR$(27);"L";CHR$(N1);CHR$(N2);

to specify the number of dots to be plotted per inch. The "L" invokes 120 dots per inch. The next two numbers give the total number of dots to be plotted on each line, using BASE 256 arithmetic. Thus, since 640 dots are needed, a value of N1 = 128 and N2 = 2 gives

$$128 + 2\,(256) = 640$$

Line 4: 27,"2".

IBM/Epson printers terminate graphics with the command string

```
CHR$(27);"2";
```

A definition file for Hewlett-Packard DeskJet and LaserJet printers takes the following appearance:

```
 11  0.749609
27,"E",27,"*t100R",27,"*r0A".HP
27,"*b80W".
27,"*rB",27,"E".
```

The HP after the period on Line 2 is essential. If the printer is one of these types, simply replace AGVIEW.DEF with this definition file and correct for the screen type.

AGCTRL

AGCTRL provides a shell program for managing the calculation from AGEDIT to AGDISP to AGPLOT to AGVIEW. The shell is invoked with the command

AGCTRL filename

If a filename is not entered on the command line, AGCTRL asks

Enter Master Input File Name

The process options available are the following:

-1	Change Master Input File Name
0	Exit to DOS
1	AGEDIT To Edit Master Input File
2	AGDISP To Integrate Equations
3	AGPLOT To Construct Plots

When AGCTRL asks

Enter Option To Invoke

the program always presents the next most logical process option in parenthesis. Pressing ENTER invokes this default.

If AGDISP or AGPLOT generates errors during program operation, AGCTRL asks

Error Exit From AGDISP/AGPLOT -- Press ENTER To Continue

to give enough time to read the screen and discover the mistake.

- AGDISP is actually invoked with the command line

AGDISP filename.INP

while AGPLOT is actually invoked with the command line

AGPLOT filename.LOG

WETBULB

The wetbulb temperature depression entry on card 0065 may be computed separately by invoking the program WETBULB. WETBULB asks for the following information, and then computes the temperature depression using the Carrier equation (Jennings and Lewis 1950):

Dry Bulb Temperature (deg F or deg C)

Height Above Sea Level (feet or meters)

Relative Humidity (0 to 100)

The U. S. Standard Atmosphere is assumed to apply, and the ASME Steam Tables relate water vapor pressure to temperature. The Carrier equation is solved by iteration.

DROPSIZE

The DROPSIZE program (Teske 1990b) permits recovery and manipulation (simple interpolation and extrapolation) of the complete drop size distribution database from Skyler and Barry 1990.

SDC

The SDC program (Teske 1989d) permits entry of drop size distribution data (such as from DROPSIZE) and combining of these data into reduced input data sets for entry into AGDISP.

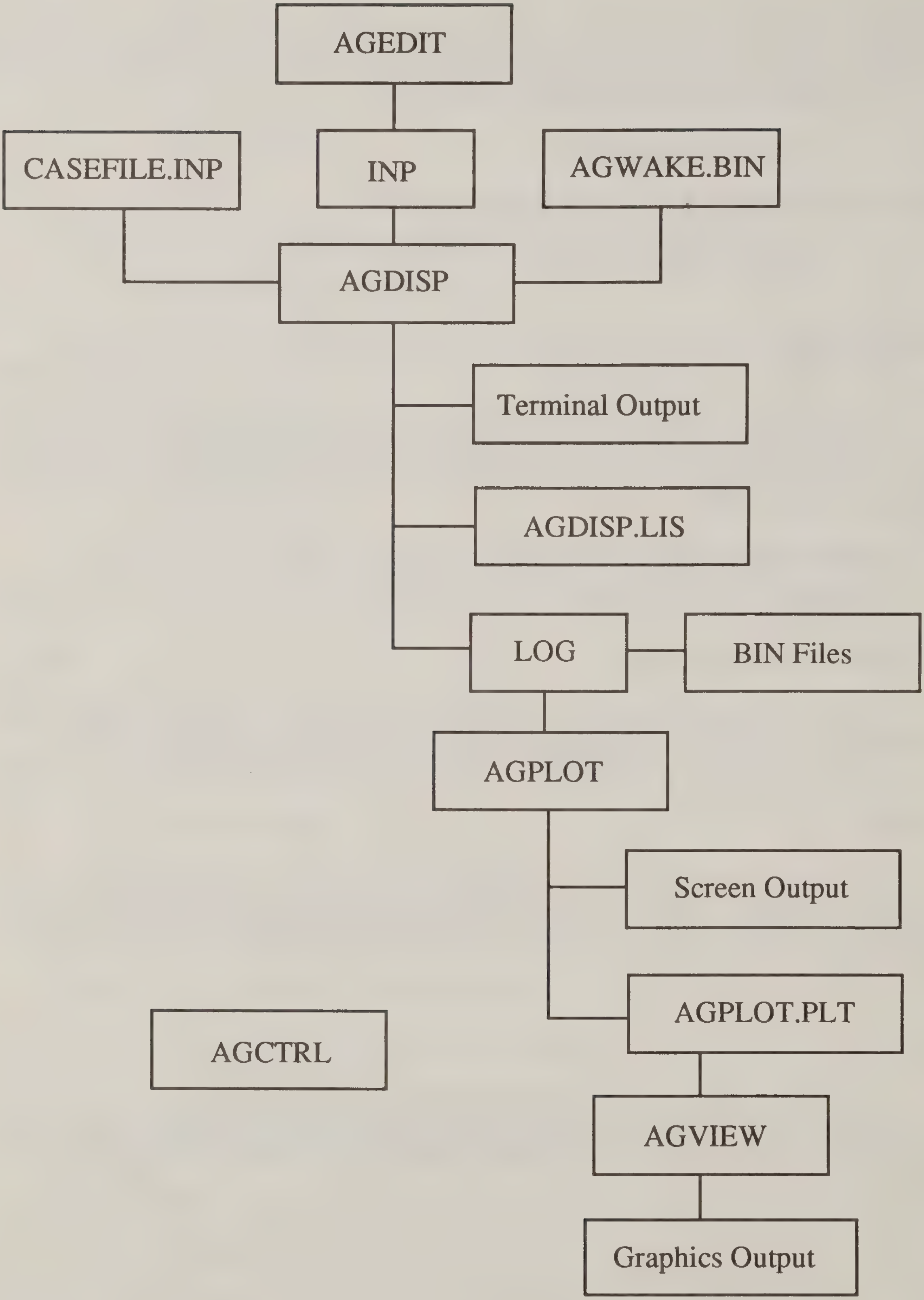

Figure 8-1 Program flowchart for operation of AGDISP and AGPLOT on personal computers.

Figure 8-2 AGVIEW results with SAMPLE.PLT. The thick border defines the maximum plotting area.

9. Atmospheric Turbulence Level

The second entry on card 0050 is the maximum value of background turbulence q^2. This value influences the growth of the variance about the mean trajectories, and the standard deviation of the deposition. The crosswind inputs on card 0028 also produce a turbulence level that is added to the card 0050 level, since a logarithmic profile generates a turbulence level of:

$$q^2 = 0.845 \left[\frac{V(z_T)}{\ln (z_T / z_o)} \right]^2 \tag{39}$$

where $V(z_T)$ is the velocity at height z_T with surface roughness z_o. Under locally neutral atmospheric conditions, the total wind velocity would be used to compute the total turbulence level by the above formula. If the atmosphere is calm, the turbulence level may be taken as 0.0 on card 0050.

For atmospheric conditions other than neutral or calm, estimates of turbulence levels may be obtained by using stability categories (Pasquill and Smith 1983, Csanady 1973, or using the Richardson number entry on card 0027). Table 9-1 presents these averaged atmospheric categories as a function of surface wind and temperature inversion, while Table 9-2 gives the range in values for turbulence as a function of surface wind and stability category. Selecting the simulation time-of-day and surface conditions permits the selection of the stability category, A through G. This category then provides the selection of turbulence values consistent with the stability. The Richardson number approach results in turbulence factors consistent with those shown in Figure 9-1.

TABLE 9-1

Stability Categories in Terms of Wind Speed, Insolation and State of Sky
(from Pasquill and Smith 1983)

Surface wind speed (m/sec)	INSOLATION			NIGHT	
	Strong	Moderate	Slight	Thinly overcast or > 4/8 low cloud	< 3/8 cloud
< 2	A	A-B	B	G	G
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Notes:

1) For A-B take average values for A and B; etc.

2) Strong insolation corresponds to sunny midday in midsummer, slight insolation to similar conditions in midwinter. Night refers to the period from one hour before sunset to one hour after dawn. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night, and for any sky conditions preceding or following the night as defined above.

TABLE 9-2

Turbulent Intensities Near Ground Level
(from Csanady 1973)

Stability Category		$q^2 / V(z_r)^2$
A	extremely unstable	0.365 - 1.2
B	moderately unstable	0.145 - 0.365
C-D-E	near neutral	0.025 - 0.145
F	moderately stable	0.015 - 0.025
G	extremely stable	0.0 - 0.015

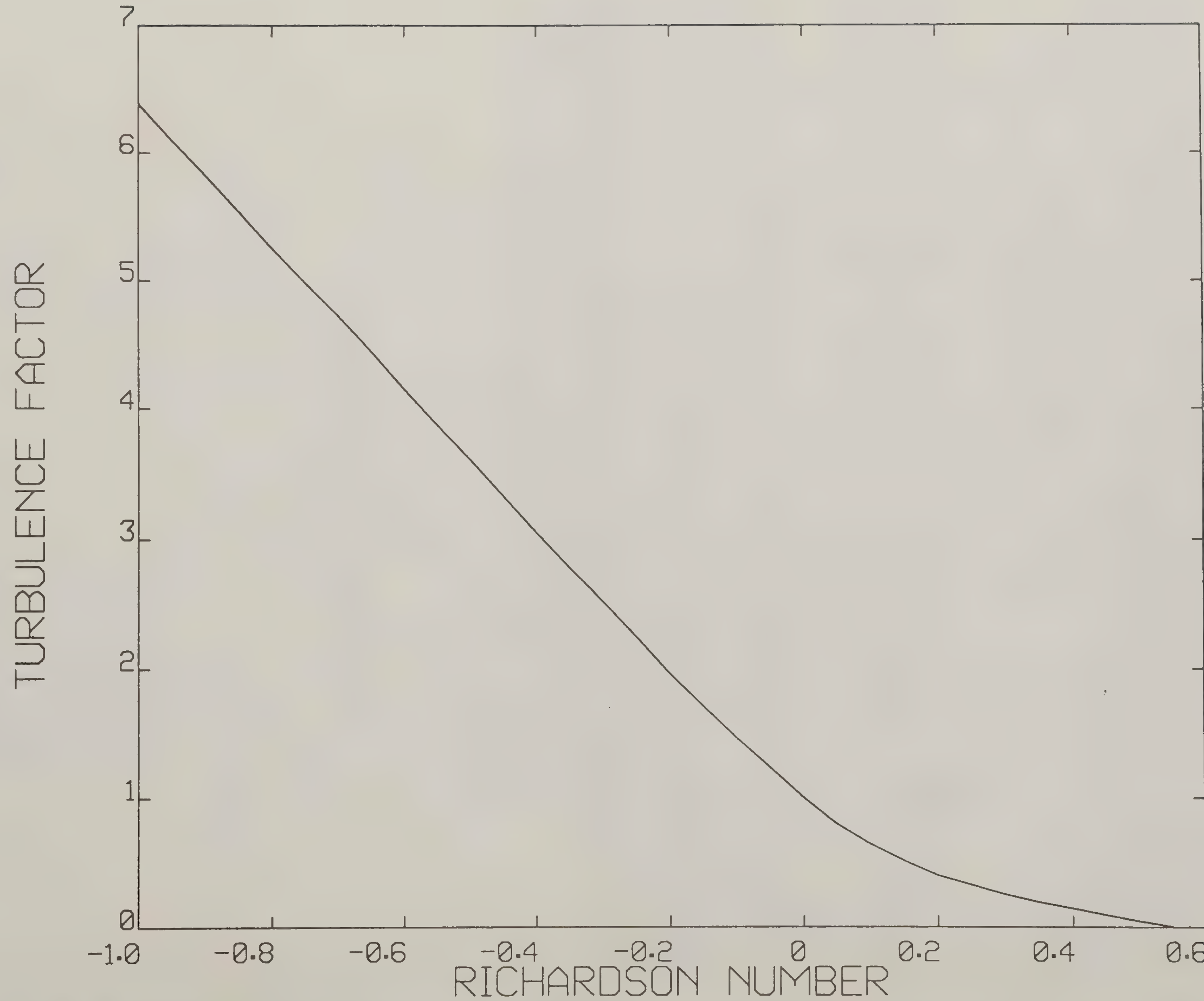

Figure 9-1 Turbulence factor in nonneutral atmospheric conditions referenced to neutral (Richardson number = 0; Bilanin, Teske and Hirsh 1978).

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Appendix A: AGDISP Subroutines

This section of the Appendix summaries the code comprising each subroutine in AGDISP. Figure A-1 presents a flowchart of AGDISP. Table A-1 highlights the common block variables used in the program.

AGDISP is the mainline program computing material motion by the Lagrangian technique. Each data entry is checked and initialization is performed. Card order is maintained by a series of error flags L20, L23, L25, etc. Free format entry requires that all data cards contain the appropriate data; otherwise, an error will be detected. All input cards generate output to the terminal screen. Integration is then performed, after which the final ground deposition is computed, including the effects of evaporation. The generated plot files are used when plotting the trajectories and deposition with AGPLOT.

AGBKG evaluates the background velocity and turbulence level at a specified point. The decay rate, based on the time constant DTAU, is first computed. The simple evaporation model of Trayford and Welch 1977, and the drag law of Langmuir and Blodgett 1946 are used. The turbulence q^2 is then computed. The turbulence may come from superequilibrium or the fixed input value modified by other models in the flow. Alternately, the turbulence may be provided in a WAKE plot file. The material-turbulence correlations are then computed. The equations are a result of the assumption of a von Karman spectral distribution (Bilanin and Teske 1984). The constants XK1, XK2, XK3 take their limiting values whenever the time constants are within one percent of each other. The correlations $< ux >$ and $< uv >$ are then evaluated. Finally, the needed information at the specified point is saved in the vector DV.

AGBOD computes the rate of change in the wide-body area, as a function of distance behind the aircraft nose, and initializes the turbulent wake parameters when the wide-body effect (with cards 0080 and 0081) is invoked. A three-point, nonuniform derivative formulation is used, with correction at the end points (the nose and tail).

AGBZD evaluates the derivatives for the time-dependent solution of the Betz roll-up methodology. The variables are the radius of the vortex core and the circulation strength of the vortex. At initialization the radius is zero and the singularity is treated by taking the appropriate limit.

AGBZG initializes the Betz roll-up procedure using the user-inputted circulation distribution stored in common block BETZ. The first section of the subroutine computes the spatial derivative of the circulation along the wing. The circulation distribution is then reexamined to locate where the slope is maximum (these become positions where vortices start rolling up) and where the slope is minimum (these become the end positions of the vortex circulation patterns). The circulation pointers to start, maximum and end for up to four vortices are then set (more than four vortices invoke an error exit from AGDISP). The initialization is completed by evaluating the derivatives and initializing all of the parameters pointing in the AGDISP code to vortex center locations, strength, canopy effect and unrolled sheet effect. The code then

establishes a vortex-dependent time step DTV vector based on one percent of the roll-up time constant.

AGBZI — integrates the Betz equations across the time step DELT entered from the AGDISP code. The first section of the subroutine establishes the time step and number of steps to integrate based on the computed values of DTV and the vortices not yet fully rolled up. Each vortex is treated separately by first predicting its new values of radius and circulation, then solving for the derivatives at these values and correcting the solution. The centroid of the vortex is computed based upon how much circulation has rolled into the vortex at each time step. The incremental movement of the vortex for each Betz time step is added to the current position of the vortex (this position may be influenced by other background features incorporated in AGDISP), and rolled-up vortices are flagged with zero sheet strength. Lastly, the unrolled sheet lengths are determined.

AGCDS — writes the input data deck at the front of the log file. If card 0005 is present, AGCDS examines the casefile to locate the proper case, then overlay these cards with any cards in the input deck. The resulting run file will be read in AGDISP as the input runstream.

AGCRS — computes the local value of turbulent energy associated with the discrete crosswind velocity profile shape entered with 0029 cards. A three-point, nonuniform derivative formulation is used to compute the velocity gradient. Locally neutral superequilibrium is assumed to compute the QV profile.

AGDAT1 — processes half of the input cards.

AGDAT2 — processes the other half of the input cards.

AGEQN — monitors the integration of the equations. Initially, all positions are stored and initial derivatives determined. Integration then proceeds step by step to the maximum time. The WAKE plot file, Betz, canopy, propeller or jet engine, helicopter and wide body are updated where applicable. Solutions terminate at the deposition height. Since the vortices move under the influence of one another and their ground images, their positions are also adjusted. Any material that impacts the surface is flagged and its final size is computed. Termination is checked for evaporation, maximum time, and ground impact; and plot save is invoked. If termination exists, transfer is returned to AGDISP; otherwise another time step is taken.

AGGLQ — is a Gauss-Legendre integration routine used to determine the area under the discrete function between starting and ending points (Carnahan, Luther and Wilkes 1969). When M equals 1, the integrand is multiplied by y to generate the spatial moment of the discrete function.

AGINT — is a linear interpolator extracting the value of the discrete function at the desired position.

AGMAT — fills the six-by-six matrix array for the unknowns < uu >, < vv >, < ww >, < uv >, < uw >, and < vw > by superequilibrium for a given value of q^2. The linear equations are solved to determine the difference between q^2 and < uu > + < vv > + < ww >.

AGPAD computes the vortex circulation reduction resulting from interactions with a canopy. Essentially, the scrubbing of the vortex acts as a drag on the wake flow field. The drag translates into an effective vortex strength smaller than the noncanopy value. In this subroutine vortices are checked for whether they have penetrated the canopy; if so, an integration across the portion of the vortex interacting with the plant area is taken, a simple time integration is performed, and the vortex strength reduction factor is computed. The reduction factors FACR and FACL modify the vortex strengths, unrolled sheet strengths, propeller swirl and helicopter effects.

AGSAV writes the step integration results from AGDISP to the plot file (mean position, standard deviation, etc.) and the line printer (all variables for all nonimpacted material). With the proper flags set, this routine will also write to the plot file and print vortex center and powerplant locations.

AGSRI evaluates the turbulence correction for nonzero Richardson number.

AGSUP is the controlling routine for superequilibrium. Given the six spatial derivatives in the AGDISP code and the local scale length, the superequilibrium equations are iterated for the values of < uu >, < vv > and < ww >. The maximum gradient is used to normalize the solver, an approximate result is selected, and then an accurate solutions is found by stepping in q until a zero crossing is found by bisection. This result produces the values of turbulent energy unnormalized by scale length and the normalizing velocity gradient.

AGSVE computes the incremental background velocity from the unrolled Betz sheets. In this case the sheets are represented by a constant circulation sheet of vorticity, and the resulting flow is analytically determined. The singularity in the vicinity of the sheet is controlled by imposing a linear profile in z. As the Betz procedure continues, the sheet becomes shorter until it is finally rolled up.

AGVEL computes the mean velocity components U, V, and W at the position (x,y,z). Each vortex, its reflecting image across y = 0 and their images across z = 0, are used to compute the overall velocity increment. The standard potential vortex velocity field producing a velocity normal to the radius vector is broken into its (y,z) components and modified by FACR and FACL for the presence of a canopy and GDKV for circulation decay. The unrolled sheet effect (with image sheets) is added, as are the helicopter, powerplant, wide body and mean crosswind modified by the canopy. Alternately, the WAKE plot file is quizzed to return the appropriate velocity components.

AGWAK processes calls for information in the WAKE plot file. The file is sequential binary, with a first record of the number of y and z mesh points, a second record of the values of the y mesh, and third record of the values of the z mesh. Following records consist of a time entry followed by all y data values for each z row for each variable. The second section recovers the WAKE plot file data for the desired time T. Interpolation between time steps is performed every one-tenth of the interval; otherwise the data arrays in common block WAKE are not updated. The file is rewound, the initial data skipped, and the pertinent time step bracketed. Linear interpolation is then performed, and the next time check is computed. When the end of the WAKE plot file is reached, the last time entry data is used for the duration of the AGDISP run. The third

section linearly interpolates the data array read from the WAKE plot file for the variable desired (V,W, q^2) at the position (y,z). A warning message is written the first time spatial extrapolation beyond the WAKE plot file grid coordinate is invoked, even though extrapolation may continue indefinitely thereafter.

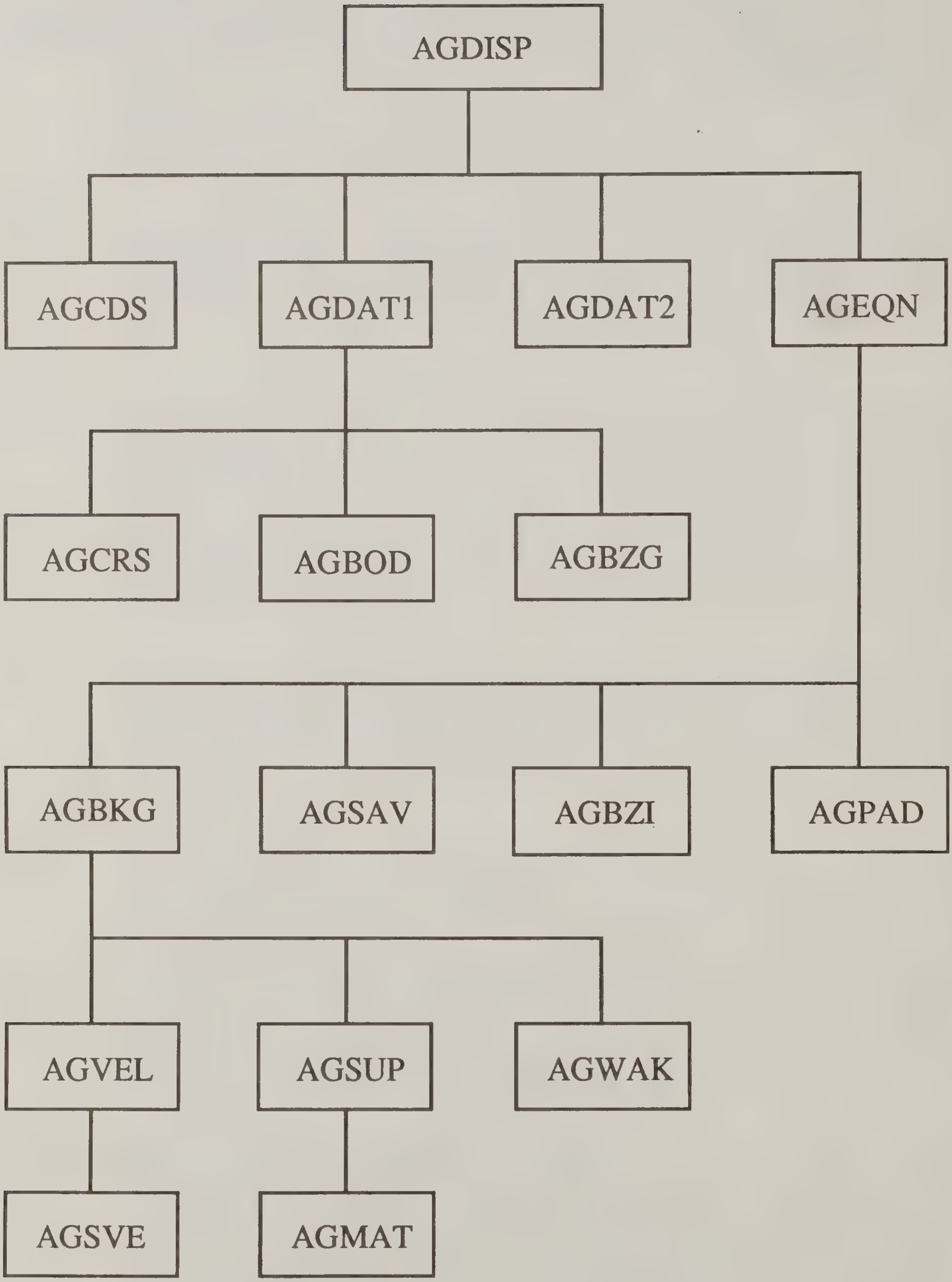

Figure A-1 AGDISP summary flowchart.

TABLE A-1: AGDISP Common Variable List

Name	Common	Description
AV	AREA	vector: plant area fraction
	SUPR	vector: superequilibrium values
	WAKE	vector: wake plot file contents
CAV	AREA	vector: canopy parameter indicates amount of material removed
CCW	WIND	cosine of crosswind angle
CEFF	AREA	canopy collection efficiency
CHF	HELI	helicopter transition factor (hover to vortex pair)
CHG	HELI	helicopter circulation factor (vortex pair)
CHQ	BODY	wide-body wake turbulence factor
CHR	BODY	wide-body wake radius factor
CHS	BODY	wide-body interpolated cross-sectional area
CHW	HELI	helicopter downwash factor (hover)
CHZ	HELI	effective surface roughness
CPUR	PROP	powerplant wake turbulence factor
CPXI	PROP	powerplant virtual origin factor
CPXIS	LOOP	saved initial powerplant virtual origin factor
CTA	TERR	cosine of terrain angle
DBOD	BODY	current diameter of wide body
DCUT	EVAP	drop diameter below which evaporation ceases
DEA	EVAP	parameterized evaporation constants (also DEB and DEC)
DEAS	LOOP	vector: parameterized evaporation constants (also DEBS and DECS)
DENF	EVAP	specific gravity
DGV	BETZ	vector: Betz circulation derivatives
DIAM	EVAP	drop diameter
DIAMV	DROP	vector: drop sizes

DIST	INPT	vertical distance to nominal height
DMASS	DROP	vector: mass fractions
DMCV	EVAP	vector: drop volume ratio at surface impact
DOV	VORT	vector: Betz roll up derivatives
DOVS	LOOP	vector: saved initial Betz roll up derivatives
DSYM	MEAN	vector: unrolled Betz sheet length left-of-centroid
DSYMS	LOOP	vector: saved initial unrolled Betz sheet length left-of-centroid
DSYP	MEAN	vector: unrolled Betz sheet length right-of-centroid
DSYPS	LOOP	vector: saved initial unrolled Betz sheet length right-of-centroid
DT	NORM	time step
DTAU	NORM	drop relaxation time
DTEMP	EVAP	wet bulb temperature difference
DTV	VORT	vector: Betz integration time step for each vortex
DZBP	INPT	incremental vertical distance from DIST to biplane wing
EDNV	NORM	vector: present drop diameter size
EDOV	NORM	vector: previous drop diameter size
FACL	MEAN	vector: plant canopy circulation reduction for left vortices
FACR	MEAN	vector: plant canopy circulation reduction for right vortices
FHEL	HELI	helicopter distance factor
FL	INTG	vector: plant area fraction integral for left vortices
FLOW	DROP	flow rate of spray system
FR	INTG	vector: plant area fraction integral for right vortices
G2PI	MEAN	vector: circulation divided by two pi
G2PIS	LOOP	vector: saved initial circulation divided by two pi
GDK	GAMD	vortex decay constant
GDKV	GAMD	vector: vortex decay factor for each vortex
GSAV	MEAN	vector: Betz average sheet circulation per unit length

GSAVS	LOOP	vector: saved initial Betz average sheet circulation per unit length
GV	BETZ	vector: Betz circulation
HHEL	HELI	initial height of helicopter rotor plane above surface
HTPAD	MEAN	plant canopy maximum height
ICLOC	SAVE	flag to indicate saving of canopy information in plot file
ICMX	CARD	number of input cards
ICV	CARD	vector: card numbers
IDLOC	SAVE	flag to indicate saving of drop size information in plot file
IOUT	SAVE	flag to force output to screen
ISW	SAVE	vector: flag indicating ground encounter
ISWC	SAVE	flag to sum number of drops hitting the ground
IWLOC	SAVE	flag to indicate saving of vertical velocities in plot file
IXLOC	SAVE	flag to indicate saving of all velocities in plot file
JHEL	HELI	dividing streamline flag
KVOR	VORT	flag indicating number of vortices not yet rolled up
LBOD	BODY	running pointer indicating position along wide body
LEVAP	EVAP	evaporation flag
LMCRS	MEAN	mean crosswind flag
LMVEL	MEAN	mean velocity flag
LPRP	PROP	flag indicating powerplant type (jet engine or propeller)
LQQSE	TURB	turbulence flag
LUNIT	INPT	English units flag
LV	INPT	vector: card flags
LX	INPT	error flag
MEV	VORT	vector: end points location for all Betz vortices
MSV	VORT	vector: starting points location for all Betz vortices
MXV	VORT	vector: maximum points location for all Betz vortices

N2FRO	DROP	"fro" flag
NBOD	BODY	number of discrete wide-body data points
NBTZ	VORT	number of Betz vortices
NCRS	WIND	number of discrete crosswind velocity data points
NDAT	CARD	data file unit number
NDEF	CARD	casefile unit number
NDRP	DROP	number of drop sizes
NENDF	WAKE	WAKE plot file record position counter
NEXTF	WAKE	WAKE plot file extrapolation flag
NGAM	BETZ	number of discrete Betz circulation data points
NLOG	CARD	log file unit number
NOUT	OUTP	screen output unit number
NPAD	AREA	number of discrete plant area fraction data points
NPLT	OUTP	plot output file unit number
NPRP	PROP	number of powerplant units
NPRT	OUTP	printer output file unit number
NPTJ	OUTP	frequency of trajectory plot output file writes
NPVL	OUTP	plot save flag for vertical velocity
NPVX	OUTP	frequency of vortices/centerlines plot output file writes
NPXX	OUTP	plot save flag for mean velocities
NSCR	CARD	temporary file unit number
NSTEP	SAVE	step number counter
NVAR	OUTP	number of nozzles
NVOR	MEAN	number of vortices
NWPF	WAKE	WAKE plot file unit number
NY	WAKE	number of horizontal points in WAKE plot file
NZ	WAKE	number of vertical points in WAKE plot file

PGBP	BETZ	biplane wing circulation factor
PSBP	BETZ	biplane wing semispan factor
PV	WIND	vector: vertical locations of crosswind velocity
QQBOD	BODY	centerline turbulence level in wide-body wake
QQMX	TURB	constant background turbulence level
QV	WIND	vector: computed crosswind turbulence level
RBOD	BODY	current radius of wide body
RHEL	HELI	helicopter blade radius
RLIM	MEAN	vortex core radius
RPRP	PROP	radius of propeller/jet flow field
RPRPS	LOOP	saved initial radius of propeller/jet flow field
S	INPT	aircraft semispan/rotor radius
SBV	BODY	vector: wide-body area
SCW	WIND	sine of crosswind angle
SPRP	TFRO	vector: rotation directions of propellers
SRV	MEAN	vector: vortex core radius
SRVS	LOOP	vector: saved initial vortex core radius
STA	TERR	sine of terrain angle
TA	INPT	terrain slope angle
TFNL	MNMX	final time value
TMAX	NORM	maximum integration time
TMCV	EVAP	vector: time of impact with surface
TR	WAKE	WAKE plot file time
UO	MEAN	aircraft flight speed
USK	MEAN	shear stress constant for crosswind evaluation
UV	WIND	vector: crosswind U velocity
UY	SUPR	y derivative of U axial velocity
UZ	SUPR	z derivative of U axial velocity

VFRAC	DROP	volatile fraction
VPRP	PROP	propeller tip speed
VPRPS	LOOP	saved initial propeller tip speed
VV	WIND	vector: crosswind V velocity
VY	SUPR	y derivative of V horizontal velocity
VZ	SUPR	z derivative of V horizontal velocity
WHEL	HELI	helicopter downwash velocity at blade plane
WY	SUPR	y derivative of W vertical velocity
WZ	SUPR	z derivative of W vertical velocity
XBOD	BODY	axial distance from trailing edge (shaft centerline) to wide body nose
XBV	BODY	vector: wide body axial distance
XO	MEAN	axial distance measured from nozzle
XOS	LOOP	saved initial axial distance measured from nozzle
XOV	VORT	vector: Betz roll up values
XOVS	LOOP	vector: saved initial Betz roll up values
XPRP	PROP	axial location of powerplants
XS	LOOP	vector: saved initial nozzle locations
YBAL	MEAN	vector: horizontal location of left vortices
YBALS	LOOP	vector: saved initial horizontal location of left vortices
YBAR	MEAN	vector: horizontal location of right vortices
YBARS	LOOP	vector: saved initial horizontal location of right vortices
YBOD	BODY	horizontal location of wide-body centerline
YBODS	LOOP	saved initial horizontal location of wide-body centerline
YHEL	HELI	horizontal location of helicopter centerline
YHELS	LOOP	saved initial horizontal location of helicopter centerline
YMMN	MNMX	minimum y value of mean trajectory
YMMX	MNMX	maximum y value of mean trajectory
YMSN	MNMX	minimum y value of spread trajectory

YMSX	MNMX	maximum y value of spread trajectory
YOV	VORT	vector: Betz roll up horizontal locations
YOVS	LOOP	vector: saved initial Betz roll up horizontal locations
YPRP	PROP	vector: horizontal location of powerplant centerline
YPRPS	LOOP	vector: saved initial horizontal location of powerplant centerline
YV	BETZ WAKE	vector: discrete stations for Betz circulation vector: horizontal points in WAKE plot file
ZBAL	MEAN	vector: vertical location of left vortices
ZBALS	LOOP	vector: saved initial vertical location of left vortices
ZBAR	MEAN	vector: vertical location of right vortices
ZBARS	LOOP	vector: saved initial vertical location of right vortices
ZBOD	BODY	vertical location of wide-body centerline
ZBODS	LOOP	saved initial vertical location of wide-body centerline
ZHEL	HELI	vertical location of helicopter centerline
ZHELS	LOOP	saved initial vertical location of helicopter centerline
ZMMN	MNMX	minimum z value of mean trajectory
ZMMX	MNMX	maximum z value of mean trajectory
ZMSN	MNMX	minimum z value of spread trajectory
ZMSX	MNMX	maximum z value of spread trajectory
ZO	MEAN	surface roughness height
ZOPAD	MEAN	plant canopy effective surface roughness height
ZOV	VORT	vector: Betz roll up vertical locations
ZOVS	LOOP	vector: saved initial Betz roll up vertical locations
ZPRP	PROP	vector: vertical location of powerplant centerline
ZPRPS	LOOP	vector: saved initial vertical location of powerplant centerline
ZREF	NORM	apparent surface height
ZV	AREA WAKE	vector: vertical locations of plant area fraction vector: vertical points in WAKE plot file

Appendix B: AGPLOT Subroutines

This section of the Appendix summarizes the code comprising each subroutine in AGPLOT. Figure B-1 presents a flowchart of AGPLOT. Table B-1 highlights the common block variables used in the program.

AGPLOT is the mainline program for plotting the results from AGDISP. The program first reads the log file, recovers minimum and maximum values and identifies plot options. The user then selects a plot option, including plotting mean trajectories, trajectories including the turbulent standard deviation, trajectories of vortices or powerplant centerlines, ground deposition, equivalent density, droplet diameter or droplet velocity. More than one option may be invoked before program exit.

AGADD computes a running total (as a function of time) of the deposition by adding contribution incrementally.

AGASC computes minimum, maximum and increment scale values to include available data and present a visually pleasing scale division. The algorithm uses a base ten power law to decide on scale divisions.

AGCAN computes the incremental Gaussian deposition through a canopy. Each released material moves through the canopy, and its deposition effect is summed and contour plotted by the user.

AGCHK verifies the appropriateness of the scaling information requested by AGPLOT of the user. In all cases the scale must increase with a positive spacing between scale divisions and an integer number of scale divisions not to exceed ten.

AGCHR plots the character strings consistent with the option selected by the user.

AGCON computes the continuous ground disposition pattern.

AGCOV computes the coefficient of variation as a function of lane separation between flight lines and overlaps deposition to generate the composite swath pattern.

AGDEP evaluates the incremental continuous deposition.

AGDFT computes the drift fraction.

AGDRP reads the selected plot file to recover the time history of a specified drop diameter undergoing evaporation, the canopy parameter or the mean velocities of a drop.

AGEQD computes the equivalent Gaussian distribution. The mean horizontal and vertical positions and standard deviations are summed over all material in the solution plane, and the figure of merit is computed.

AGEQG interprets the selected plot file to construct an equivalent Gaussian profile distribution at every time step. Two passes are made through the plot file.

The first pass computes the equivalent Gaussian, figure of merit and vertical velocity criterion at every time in the plot file, and displays to the screen the points of maximum and minimum figure of merit, material impact with the surface, and equivalent Gaussian impact with the surface. From this information the maximum figure of merit is determined and the program locates that time in the second pass to create the equivalent plot.

AGEQP sets up and plots the equivalent Gaussian and material isopleths.

AGIMP computes the velocity normal to the collection device, the impaction parameter, impaction efficiency and incremental material deposition in a time step.

AGNUM converts a real number into a character string.

AGOPN opens a selected BIN plot file.

AGPLT is the plotting subroutine that uses graphics subroutine calls to perform the actual plotting. The screen is first cleared, then axes are established and plotted and a wing schematic is drawn. The plot file is read so that nine points are plotted at a time, drawing the mean trajectories, standard deviation paths, vortices and powerplant centerline paths, tag markers at a desired interval, array profiles (including ground deposition), and equivalent Gaussian profiles.

AGRPF rereads the front of the log file to recover input card data for crosswind velocity or plant area profiles.

AGSET initializes scale sizes for plotting options.

AGSPD uses the stored plot file variables to determine the plotting coordinates of the standard deviation, normal to the instantaneous direction.

AGSRF oversees computation of Gaussian deposition on a specified collection device at a specified location (y,z), with a specified unit normal.

AGSRT determines the scaling to recover the desired deposition units.

AGSUM integrates the deposition along the surface.

AGVMD computes the volume and number median diameters for the selected ground deposition.

AGVRF computes the flux of material through a specified vertical surface.

Graphics calls on the Data General invoke GKS subroutine calls. They include the following:

GKS_CLEAR clears the graphics screen.

GKS_CLOSE ends the graphic session.

GKS_DRAW connects the data points with straight lines after setting up the axes.

GKS_GPL	plots the data points.
GKS_OPEN	initializes the graphics session.
GKS_Q_WS_WIN	returns the pixel size of the plotting device.
GSK_QPRINT	sends hardcopy to the output device.
PLDG	plots pixel data.

Screen calls on the Data General invoke the following subroutine calls:

FREAD	recovers real number information from the user.
IREAD	recovers integer number information from the user.
SCREEN_INIT	initializes the screen.
SCROLL	perform a scroll of the data screen.
SREAD	recovers character information from the user.
SSCREEN	rapidly replaces screen contents.
SWRITE	writes information to the screen.

Graphics calls on VAX and on IBM PC/XT/ATs are invoked with Tektronix 4025 calls. These calls write plot data to the screen or a data file for later viewing. The subroutines invoked during the running of AGPLOT include the following:

PLHC	completes the plot.
PLLN	sets the line type.
PLNT	sets up scale notation and labels.
PLPL	plots the data points (connected by straight lines).
PLSC	initialized the graphics area and scale increments.
PLST	writes a character string.
PLTT	establishes the default graphics parameters.

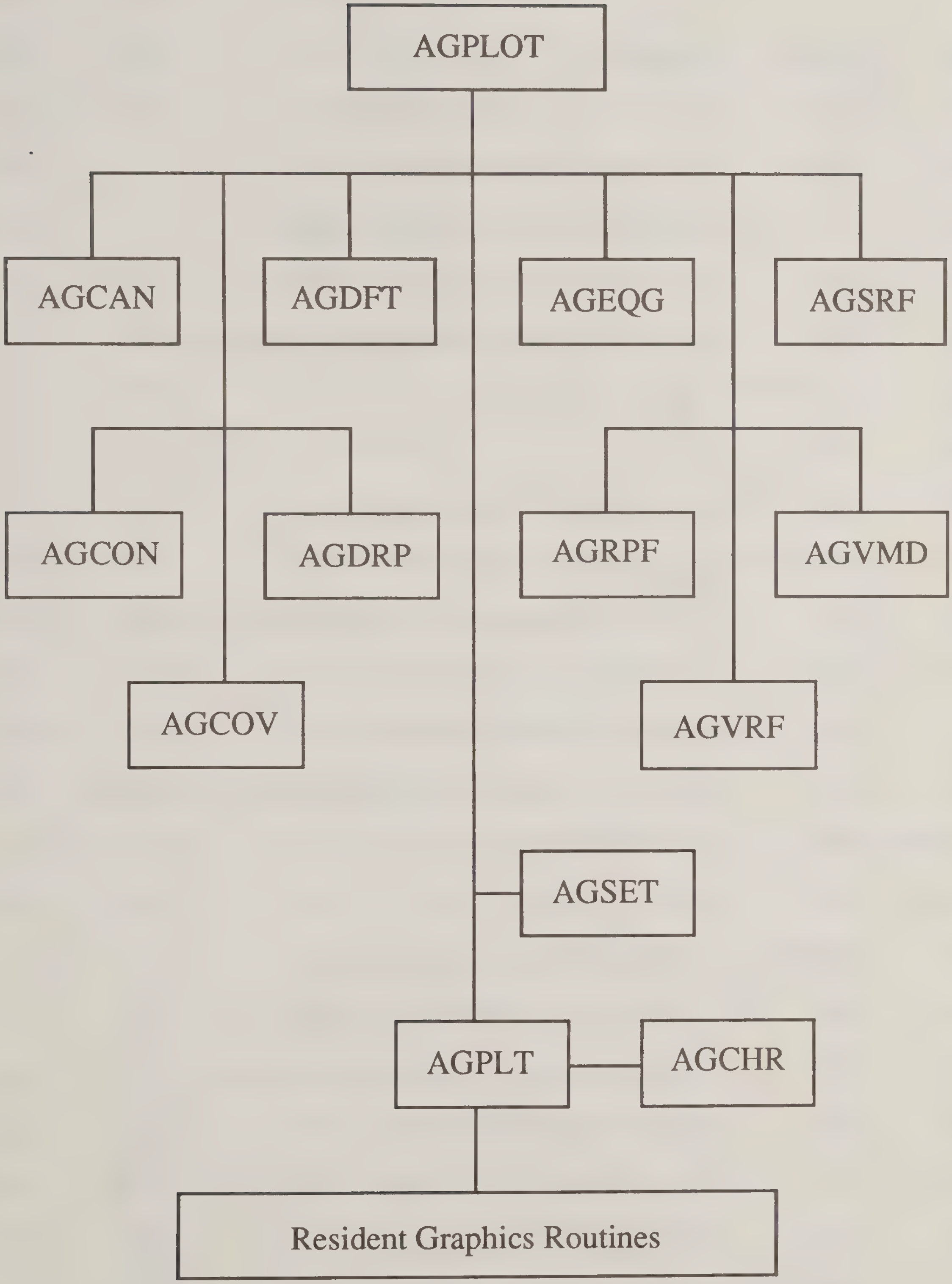

Figure B-1 AGPLOT summary flowchart.

TABLE B-1: AGPLOT Common Variable List

Name	Common	Description
AV	PVEC	vector: solution values for plotting
CBAR	EQGN	equivalent Gaussian magnitude
CNUM	NUMB	displayed number for several plot options
CVEC	PVEC	vector: VMD/NMD/canopy intermediate values
DCV	EQGN	vector: drop diameter factors for equivalent Gaussian
DELT	PLOT	tag time increment
DIAM	SURF	drop size
DIAMT	SURF	collector significant dimension
DIAMV	DROP	vector: drop diameter
DIST	PLOT	initial vertical distance from surface to aircraft wing
DMASS	DROP	vector: mass fraction
DY	CONT	y horizontal scale increment
DZBP	PLOT	incremental vertical distance from DIST to biplane wing
FLOWR	DROP	spray system flow rate
FNAME	FILE	master file name
FOM	EQGN	equivalent Gaussian figure of merit
GGRD	STOP	vector: ground and canopy deposition values
GTEM	PVEC	vector: temporary value array for vertical flux
GVEC	AVEC	vector: multiple array vector
HTPAD	PLOT	canopy height
ICOL	SURF	flag indicating collector type
ICV	EQGN	vector: surface impact flag
IOPT	PLOT	plot option number
ISW	PVEC	vector: surface impact flag

ITYP	AVEC	deposition scale flag
ITYPS	NUMB	flag indicating CNUM type
IVAR	PLOT	nozzle number flag
IVEC	PLOT	drop velocity flag
JNAME	FILE	number of characters in FNAME
KGRD	STOP	vector: number of entries in YGRD and GGRD
KTYP	STOP	vector: flag indicating ITYP for GGRD
KVOL	STOP	vector: flag indicating volatile/nonvolatile for GGRD
L2FRO	DROP	flag indicating selection of "to" or "fro" direction
LAPLT	PLOT	array plot flag
LCLOC	FLAG	flag indicating canopy information in plot file
LDLOC	FLAG	flag indicating drop size information in plot file
LDROP	DROP	flag indicating selection of drop size
LEPLT	PLOT	equivalent Gaussian distribution plot flag
LGRID	DROP	flag indicating selection of grid autoscale
LMPLT	PLOT	mean trajectory plot flag
LNVOL	DROP	flag indicating selection of volatile or nonvolatile contribution
LPRP	PLOT	flag for powerplant centerlines to plot
LSCAL	DROP	flag indicating selection of deposition scale units
LSPLT	PLOT	standard deviation trajectory plot flag
LTPLT	PLOT	tag plot flag
LVEL	PLOT	number of variables present on plot file
LVOR	PLOT	flag for vortex centroids to plot
LVPLT	PLOT	vortices/powerplant trajectory plot flag
LWLOC	FLAG	flag indicating saving of vertical velocities on plot file
LXLOC	FLAG	flag indicating saving of all velocities in plot file
N2FRO	DROP	"fro" direction flag

NDMN	DROP	minimum drop size file indicator
NDMX	DROP	maximum drop size file indicator
NDRP	DROP	number of drop sizes
NINU	OUTP	terminal input unit number
NLOG	OUTP	log file unit number
NPLT	OUTP	plot input file unit number
NOUT	OUTP	screen output unit number
NSAV	OUTP	graphics output unit number
NVAR	DROP	number of nozzles
NVEC	AVEC	number of points in array plot vectors
NVMD	CONT	drop size increment pointer
PV	PVEC	vector: powerplant locations for plotting
S	PLOT	aircraft semispan/rotor radius
SPV	EQGN	vector: standard deviation for equivalent Gaussian
TA	PLOT	terrain slope angle
TEMND	CONT	scale factor
TMAXV	DROP	vector: maximum simulation times
TTA	PSPD	tangent of terrain angle
UO	PLOT	aircraft flight speed
VFRAC	DROP	volatile fraction
VLV	PVEC	vector: left vortex locations
VRV	PVEC	vector: right vortex locations
XN	SURF	collector axial surface normal
YC	SURF	collector horizontal location
YCB	EQGN	equivalent Gaussian horizontal location
YCV	EQGN	vector: horizontal centerline locations for equivalent Gaussian
YGRD	STOP	vector: ground and canopy deposition horizontal scales

YMAX	PLOT	horizontal axis plot scale maximum
YMIN	PLOT	horizontal axis plot scale minimum
YMMNV	DROP	vector: minimum horizontal value for mean trajectories
YMMXV	DROP	vector: maximum horizontal value for mean trajectories
YMN	CONT	YMIN for continuous deposition
YMSNV	DROP	vector: minimum horizontal value for spread trajectories
YMSXV	DROP	vector: maximum horizontal value for spread trajectories
YN	SURF	collector horizontal surface normal
YSB	EQGN	equivalent Gaussian horizontal standard deviation
YTEM	PVEC	vector: temporary horizontal array for vertical flux
YVEC	AVEC	vector: horizontal array vector
ZC	SURF	collector vertical location
ZCB	EQGN	equivalent Gaussian vertical location
ZCV	EQGN	vector: vertical centerline locations for equivalent Gaussian
ZMAX	PLOT	vertical axis plot scale maximum
ZMIN	PLOT	vertical axis plot scale minimum
ZMMNV	DROP	vector: minimum vertical value for mean trajectories
ZMMXV	DROP	vector: maximum vertical value for mean trajectories
ZMSNV	DROP	vector: minimum vertical value for spread trajectories
ZMSXV	DROP	vector: maximum vertical value for spread trajectories
ZN	SURF	collector vertical surface normal
ZREF	PLOT	surface reference height
ZSB	EQGN	equivalent Gaussian vertical standard deviation
ZTEM	PVEC	vector: temporary vertical array for vertical flux
ZVEC	AVEC	vector: vertical array vector